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APPLICABILITY OF THE MEYERS PROCESS FOR CHEMICAL DESULFURIZATION OF COAL

INITIAL SURVEY OF FIFTEEN COALS

TRW Systems Group

PREPARED FOR
Environmental Protection Agency

April 1974

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16. ABSTRACT

The report gives detailed experimental results of applying chemical desulfurization technology to a variety of U.S. coals. Run-of-mine coal samples were collected from 15 U.S. coal mines in 11 states. Each coal was treated separately by the Meyers Process (ferric sulfate extraction) and float-sink fractionation (physical coal cleaning). The Meyers Process removed 83-99% of the pyritic sulfur (40-64% of the total sulfur) from all the coals that contained sufficient pyritic sulfur for accurate sulfur determination. Four coals were reduced to less than 1.0% total sulfur by the Meyers Process, and one coal was reduced to less than 1% total sulfur by physical cleaning. Except for one mine, the Meyers Process removed significant increments of sulfur over that removed by physical cleaning. The Meyers Process also removed significant amounts of selected trace elements along with the pyrite.

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Coal	Stationary Sources	8G, 21D
Coal Preparation	Meyers Process	8I
Desulfurization	Ferric Sulfate Extraction	7A
Sulfur	Float-Sink Fractionation	7B
Pyrite Trace Elements		

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ABSTRACT

Run-of-the-mine coal samples were collected from each of 15 US mines located in 11 states from New Mexico and Montana to West Virginia and Pennsylvania. Each coal was treated separately by the Meyers Process (ferric sulfate extraction) and float-sink fractionation (physical cleaning). The Meyers Process removed 83-99% of the pyritic sulfur (40-64% of the total sulfur) from all of the coals which contained sufficient pyritic sulfur for accurate sulfur determination (i.e., greater than 0.3% w/w). Four of the coals were reduced to less than 1% total sulfur by the Meyers Process while one of the coals was reduced to less than 1% total sulfur by physical cleaning (1.90 float material, 14 mesh x 0). With the exception of one mine, the Meyers Process removed significant to very large increments of sulfur over that separable by physical cleaning. Significant amounts of As, Be, Cr, Mn, Ni, Se and Zn were removed along with the pyrite by the Meyers Process.

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1.0 CONCLUSIONS

1. Only one of the fifteen run-of-mine (ROM) coals investigated in this survey met the Clean Air Act sulfur oxide emission standard of 0.6 lbs* of sulfur/10^6 btu for new stationary combustion sources.

2. The process for chemical removal of pyritic sulfur from coal (Meyers Process) was demonstrated to be capable of removing:

   a) 89 to 95% of the pyritic sulfur (44 to 59% of the total sulfur) from the six Appalachian Basin coals experimentally investigated in the survey program. An additional coal - from the Walker Mine - contained insufficient pyritic sulfur, 0.07% w/w, for measurable evaluation in this program.

   b) 96 to 99% of the pyritic sulfur (44 to 57% of the total sulfur) from the three Eastern Interior Basin coals investigated.

   c) 98% of the pyritic sulfur (64% of the total sulfur) from the single Western Interior Basin coal investigated.

   d) 57 to 82% of the pyritic sulfur from the four Western coals investigated. Of these four samples only coal from the Colstrip Mine contained sufficient pyritic sulfur, 0.34%, of which 82% was removed, to give reasonably accurate results.

   e) significant amounts of As, Be, Cr, Mn, Ni, Se and Zn.

3. Seven potentially hazardous trace elements - Ag, Be, Cd, Hg, Sb, Sn and Se - were generally present in the coals studied in amounts that may be of minimal environmental significance (<3 ppm) from coal combustion facilities.

4. The Meyers Process reduced the total sulfur content of four coals under investigation to below 1.0% (three of these were reduced to 0.7% or less).

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*EPA policy is to express all data in Agency Documents in metric units. Because implementing this practice will result in undue cost, NERC/RTP is providing conversion factors for the particular non-metric units used in this document. These factors are located on page 79.

5. Most coals showed an increase in heat content after Meyers Process treatment. For the Appalachian and some of the Eastern Interior Basin coals, this heat content rise amounted to 6-9% of the initial heating value. When calculated on a dry mineral matter free basis,a heat content loss of 2.8-8.3% was found for Western coals, a heat content change of +.4 to -5.1% was found for Interior Basin coals, and a heat content change of +2.6 to -4.6% was found for Appalachian coals.

6. Ash removal, in addition to that accounted for by the pyrite decrease, was observed in varying degrees for all coals.

7. Sulfate retention on some of the treated coal samples required additional washing to reduce the sulfate levels to values equal to or lower than the starting sulfate contents.

8. Float-sink testing showed that conventional coal cleaning could reduce only one of the coals tested to a sulfur content value as low as that obtainable by the Meyers Process (Jane Mine - but with 15% btu loss).

9. The extraction of seven coals was studied with p-cresol, with the results showing no significant organic sulfur removal.

2.0 RECOMMENDATIONS

1. The Meyers Process should continue to be tested on additional coals from all parts of the U.S. in order to further define the applicability of the process for meeting legislated sulfur oxide pollution control standards.

2. Future studies should include removal of pyritic sulfur from various coal size and density fractions typical of the output of coal preparation units for the purpose of establishing optimum combinations of the Meyers Process with current coal handling and treatment practice.

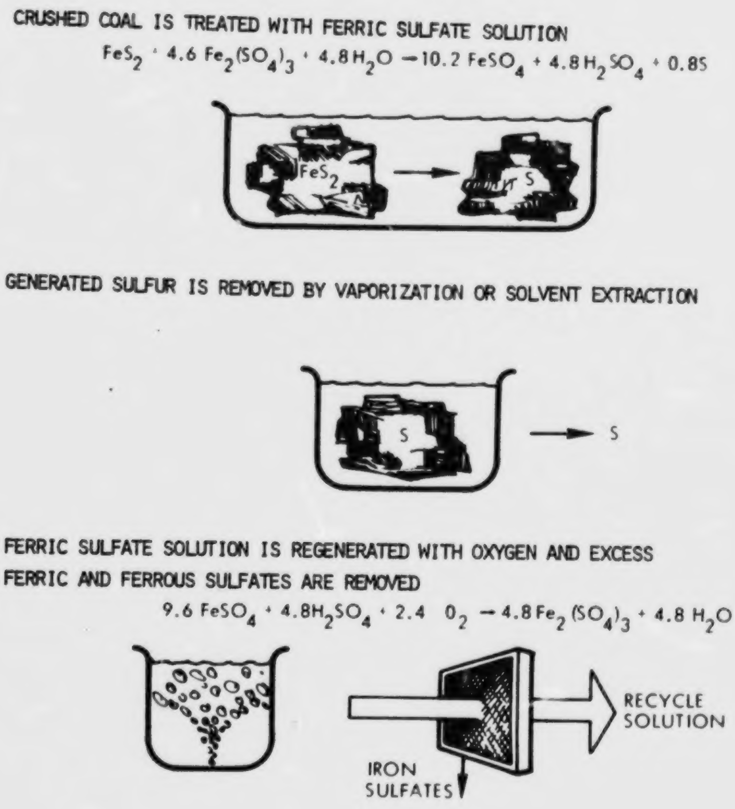
3. Process parameters necessary to effect optimum residual elemental sulfur and sulfate removal as well as the fate of major acid soluble ash constituents such as calcium, magnesium and non-pyritic iron should be studied.

4. Near-term emphasis should be placed on Eastern coal since the process applicability as defined by the first coals extracted appears to be greatest for this region of the country, and since 60% of current coal production in the U.S. is mined in this region.

5. Further studies on the utilization of p-cresol to selectively leach organic sulfur from U.S. coals should not be performed.

3.0 INTRODUCTION

The Meyers Process is a new and economically attractive method for the desulfurization of coal for control of sulfur oxide emissions from stationary combustion sources. The process utilizes a regenerable aqueous ferric sulfate leaching unit to chemically convert and remove the pyritic sulfur content of coal as elemental sulfur and iron sulfate. In addition, the ash content of the coal is decreased by 10 to 40% and the heat content per unit weight increased by as much as 8%. The process chemistry for both leaching and regeneration is outlined in Figure 1.


CRUSHED COAL IS TREATED WITH FERRIC SULFATE SOLUTION

$$FeS_2 + 4.6\ Fe_2(SO_4)_3 + 4.8\ H_2O \rightarrow 10.2\ FeSO_4 + 4.8\ H_2SO_4 + 0.8S$$

GENERATED SULFUR IS REMOVED BY VAPORIZATION OR SOLVENT EXTRACTION

FERRIC SULFATE SOLUTION IS REGENERATED WITH OXYGEN AND EXCESS FERRIC AND FERROUS SULFATES ARE REMOVED

$$9.6\ FeSO_4 + 4.8H_2SO_4 + 2.4\ O_2 \rightarrow 4.8 Fe_2(SO_4)_3 + 4.8\ H_2O$$

Figure 1. Pyritic Sulfur Removal Process Chemistry

The detailed chemistry, reaction kinetics, and engineering and economic viability of the process were established under an Environmental Protection Agency sponsored bench-scale program (Contract No. EHSD 71-7) for evaluation of the Meyers Process (1). Because of the success of the bench-scale program and the national need for sulfur oxide control technology, the process is now in a pilot plant design phase.

Other major methods which offer promise for the control of sulfur oxides from coal burning stationary sources include: flue gas scrubbing, coal liquefaction and physical cleaning. These alternative methods are compared to the Meyers process in the following discussions.

Chemical desulfurization has some inherent advantages over flue gas scrubbing for sulfur oxide control in that, a) application of this process requires no major modification of existing or new power plant facilities or of power plant operation, b) sulfur is removed from coal directly as elemental sulfur (Figure 2) and iron sulfate, and in relatively small amounts (e.g., approximately 200,000 tons/yr for reducing 3.2×10^6 tons/yr of a 4% sulfur coal to 0.8% sulfur vs 1,000,000 tons/yr of a gypsum sludge

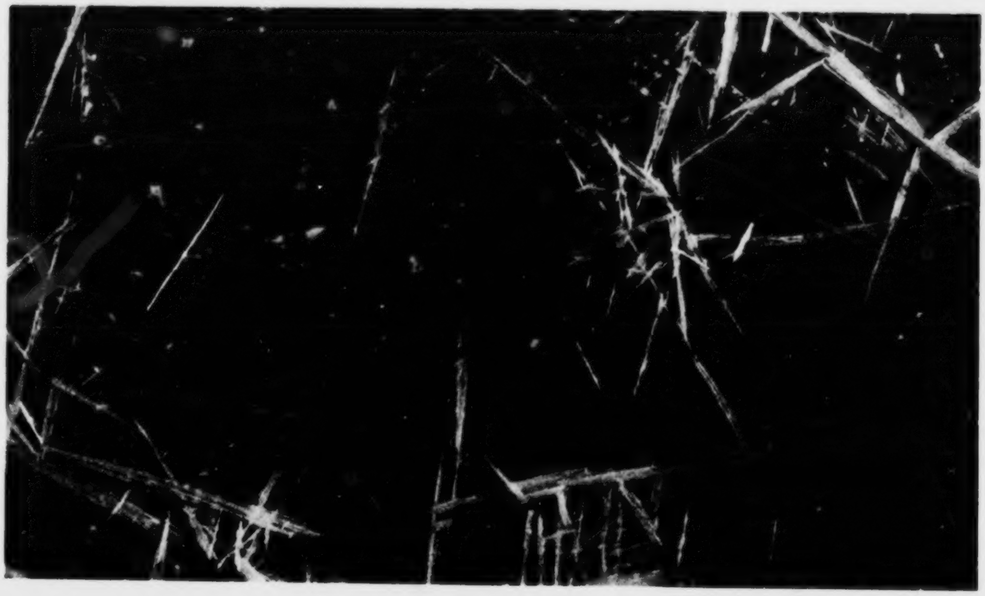


Figure 2. Sulfur Product from Pyrite Removal Process (1X)

throwaway material for comparable sulfur oxide removal using non-regenerable limestone scrubbing). This second advantage does not apply, of course, when comparing the Meyers Process to the regenerable flue gas scrubbing processes now under investigation. The iron sulfates from the Meyers Process may be converted to an insoluble basic iron sulfate form by calcining, may be used to start up additional process plants, or may possibly be sold as a chemical product in some locations.

This process has advantages over coal liquefaction in that (a) operation under conditions of 100°C to 130°C, ambient to 100 psig is possible, while coal liquefaction requires temperatures of 400-500°C and pressures in excess of 1,000 psi; (b) a thermal efficiency of greater than 90% is obtained compared with a thermal efficiency for coal liquefaction of approximately 70-80% (this is an important factor in the conservation of the overall U. S. energy base); and (c) only air or oxygen is required as a consumable chemical, while liquefaction requires at least 1 to 2% by weight hydrogen or synthesis gas and for catalytic liquefaction a significant amount of catalyst is found to be unrecoverable. However, coal liquefaction is capable of reducing a broader range of coals to meet the Clean Air Act standards.

The Meyers Process has advantages over physical cleaning (or separation by physical methods of coal into rock rich and rock lean portions) in that (a) large quantities of waste products are not generated (e.g., for typical physical cleaning of coal, which is basically practiced to remove non-combustible rock, 5-10% of the carbon content of the coal is discarded along with the rock rich fraction giving rise to a secondary pollution problem of acid drainage from tailings, while for deep cleaning of coal, whose purpose would be to remove a large quantity of the pyritic sulfur, up to 30% or 40% by weight of the coal may be discarded giving rise not only to an acid drainage problem but to physical and combustion hazards due to the mass of reject; (b) pollutants are converted into small amounts of potentially useful chemicals - elemental sulfur and iron sulfate; and (c) consistent and greater reductions in overall pyritic sulfur content can be achieved.

Because of the widespread application of physical cleaning techniques for removal of non-combustible rock from coal (which includes some pyrite), this process deserves to be compared directly to the Meyers Process for applicability in meeting the standards of the Clean Air Act. Indeed, in actual practice simple coal washing may well be used prior to the Meyers Process to provide an improved coal product containing both minimum ash and minimum sulfur and optimum heating value.

Therefore, the present program for a "Survey of the Applicability of the Meyers Process for Chemical Desulfurization of U. S. Coals" (Contract No. 68-02-0647) was established to determine the potential of the Meyers Process to desulfurize United States coals and to establish a comparison with physical cleaning of coal. Significantly, both processes are amenable to simple laboratory testing - the Meyers Process through a chemical leach with ferric sulfate solution as described in Figure 1, and physical cleaning through utilization of float-sink testing in dense media. In addition, it was a further objective of the program to determine the fate during chemical leaching of 18 minor elements commonly found in domestic coals.

The potential of this process to provide a means to meet Federal standards of performance for new stationary sources is high. The Appalachian Coal Basin is an illustrative example. This coal region has particular importance as it provides 60% of current United States coal production, with 22 billion tons of identified and recoverable reserves, and is also the major single area of U. S. sulfur oxide air pollution. Presently, approximately 90% of the coal mined for utility use in the Appalachian Basin exceeds the sulfur content required to meet the sulfur dioxide emission standard of no greater than 1.2 lbs of SO_x emitted per million btu's of input energy. However, on the basis of sulfur forms data, application of the chemical removal process can increase the quantity of Appalachian coal capable of meeting the performance standard by a factor of four, to nearly 40%, at 95% pyritic sulfur removal (this amount of removal was achieved for all four coals tested in the previous bench-scale program and for most coals tested under this applicability study). In addition, many of the Appalachian coals could meet state standards for existing sources using the Meyers Process.

There are 23 major coal mining districts in the United States with several hundred identifiable coals, all of which vary significantly in composition, i.e., ash content, carbon content, sulfur content, pyrite distribution, etc. Thus, in order to establish the applicability of chemical removal of pyritic sulfur from coal process technology for sulfur oxide pollution control in the United States, the amount of sulfur which may be removed from representatives of the widest possible variety of coals must be determined. The present survey program evaluated 15 U.S. coals from mines in the Appalachian, Eastern Interior, Western Interior and Western areas of the United States.

This report of the survey program contains data on over 70 coal extractions and 180 coal float-sink determinations, necessitating more than 2500 separate chemical and spectroscopic analyses. Therefore, the following guide is provided for the readers who wish to focus their attention in a specific area. Program results are presented in five major areas:

- Selection, sampling and preparation of coals
- Chemical removal of pyritic sulfur
- Float-sink studies
- Organic sulfur extraction
- Evaluation of trace element changes

These sections are followed by references, a glossary, and appendices. Those readers desiring to review the experimental data obtained for removal of pyritic sulfur from coal are directed to Sections 4.1, 4.3 and 4.4 (pp.9, 30 and 53, respectively), as well as the appendix tables cited in these sections. Those readers desiring the selection criteria of coals for the survey are directed to Section 4.2, while those readers interested in experimental methods and sample techniques and preparation are directed to Sections 4.2 and 4.3 (pp.13 and 30, respectively). Float-sink (washability) studies are reported in Section 4.4 (pp.53). Extraction of organic sulfur is presented in Section 4.5 (pp.57), and the trace element studies are presented in Section 4.6 (pp.63).

4.0 PROGRAM RESULTS

The program results are presented in the six sections to follow: Summary, Selection and Sampling, Chemical Removal of Pyritic Sulfur, Float-Sink Testing, Extraction of Organic Sulfur, and Trace Elements in Coal.

4.1 SUMMARY

The Meyers Process is operable over a wide range of conditions (e.g., 100°C-130°C, coal top sizes of 1/4" to 200 mesh x 0, pressures from ambient to 100 psig, and both with and without concurrent regeneration of leach solution). Detailed discussion of the data obtained utilizing these variations is presented in the final report for the bench-scale program (1).

A set of reaction conditions amenable to laboratory testing which is within the above range of variables was selected for this survey program. More specifically, testing was conducted at approximately 100°C and ambient pressure, and the leach solution was periodically changed in order to maintain reasonable reaction rates. Each coal was found to require specific conditions for maximum pyrite removal and total sulfur content reduction relative to one or more of the following factors: reaction time, coal particle size, degree and type of washing for sulfate removal and excess utilization of ferric ion. More than one reaction trial was often necessary for identification of the conditions for high removal.

A summary of the best results to date for chemical removal of pyritic sulfur and the optimum results for conventional coal washing (float-sink evaluation) are shown in Table 1. The table describes the results from the coals which contained sufficient pyritic sulfur for accurate sulfur removal determination (i.e. > 0.3% w/w). Actual total sulfur values before and after chemical removal are shown in columns 2 and 3. These may be compared with the column 4 total sulfur values which could be obtained for full process optimization (at 95% pyrite removal with no increase in starting sulfate or measured organic sulfur content). Thus for

Table 1.

Summary of Pyrite Removal Results.

Mine	% Sulfur w/w in Coal[a]			Meyers Process Pyrite Conversion % w/w	Meyers Process Total Sulfur Decrease % w/w	% Sulfur in Coal[b] After Float-Sink
		After Meyers Process				
	Initial	Current Results	95% Removal[c]			
1. Colstrip	1.0	0.6	0.7	83	40	-
2. Warwick	1.3	0.7	0.3	95	54	1.0
3. Jane	1.7	0.7	0.5	91	59	0.8
4. Orient No. 6	1.8	0.9	0.5	96	44	1.4
5. Humphrey No. 7	2.5	1.4	1.1	91	44	1.9
6. No. 1	3.1	1.5	1.2	90	52	2.3
7. Fox	3.5	1.5	0.9	89	58	2.0
8. Camp 1 & 2	4.2	2.1	1.8	99	50	2.9
9. Eagle No. 2	4.3	2.1	1.9	98	51	2.9
10. Egypt Valley	6.3	2.7	1.7	93	57	4.6
11. Weldon	6.4	2.3	1.4	98	64	3.8

[a] Dry, moisture-free basis.

[b] 1.90 Float material, 14 X 0 mesh, is defined here as the limit of conventional coal cleaning.

[c] Sulfur content of coal at 95% Pyrite Removal and no increase in sulfate or measured organic sulfur content.

example, although 99% pyrite conversion was obtained for the Camp Nos.1&2 mines,the total sulfur was reduced to 2.1%, not the theoretical 1.8%, due to a slight increase in other sulfur forms.

However, it can be seen that for approximately one-half of the coals near optimum results have already been obtained (Mines 1, 3, 5, 6, 8 and 9 are reduced to within 0.3% sulfur of optimum results), but for the remaining mines, additional processing improvements are necessary to reach near optimum values for total sulfur removal. These improvements could include higher temperature operation, more efficient sulfate removal, etc. However, in each case the Meyers Process reduced the total sulfur content of the coals to values lower than that obtainable by conventional coal cleaning (compare columns 3 and 7). In most cases, substantial differences were found.

Four of the coals treated by the Meyers Process were reduced to total sulfur values below 1% (Mines 1-4), and Mines 1-3 were reduced to sulfur levels near the Clean Air Act standard for New Stationary Sources of .6-.8% sulfur. The total sulfur removed after Meyers Process treatment varied from 40-64% removal with an average of approximately 50% (column 6), and pyrite conversions (Column 5) averaged 93% for the coals shown in the Table. Trace element analyses were performed (for 18 trace elements) in triplicate on the starting coal and on each of three treated coal samples on each of three treated coal samples for ten of the coals surveyed. The results showed that arsenic, beryllium, chromium, lithium, manganese, nickel, lead, selenium and zinc could be substantially removed from many of the coals during the Meyers Process treatment. Arsenic, beryllium, manganese, nickel, lead and zinc were particularly noteworthy as having a high degree of removal for most coals where they were present in measurable quantities.

Studies were also performed on the use of p-cresol extraction for removal of an organic sulfur rich portion of the coal. This method had been studied in the bench-scale program (1) and found to show some promise, but the results were not clear. Extraction of seven of the fifteen survey coals indicated no measureable partitioning of organic sulfur by p-cresol.

The results are presented in detail in the following five sections and in the cited Appendix divisions.

4.2 SELECTION, SAMPLING AND PREPARATION OF COALS

TRW, in consultation with the Environmental Protection Agency Project Officer, selected fifteen coal mines which were sampled on the basis of the following criteria:

(a) widest possible variety of coal beds, coal regions and coal rank,

(b) high production and reserves,

(c) sulfur content in coal sufficiently high to require control of sulfur oxide emissions from combustion.

The selected coal mines, the annual production of each mine in 1972, and the analysis summary of each coal sample are given in Tables 2 and 3. The following sections of this report present the rationale for selection, a discussion of the coals and mines selected, a description of the sampling of the coals, and a review of the sample preparation for testing at TRW.

4.2.1 Selection of Coals

4.2.1.1 Rationale

For the original program (EPA Contract EHSD 71-7)(1) two coals were selected from the Appalachian basin and two from the Eastern Interior basin. In the Appalachian basin the coals were from the Pittsburgh and Lower Kittanning seams while in the Eastern Interior coal basin the coals were from the No.5 and No.6 seams.

Some of the background information which was utilized to aid in the selection of the fifteen coals for this study is presented below in three paragraphs: Previous Production by State, Distribution of Coal Reserves and Distribution of Sulfur Content.

- Previous Production by State - Figure 3 shows the percentage distribution of the cumulative production of coal in the United States up to January 1, 1967. In descending order of production, the six most productive states were: Pennsylvania, West Virginia, Illinois, Kentucky, Ohio and Indiana. These states have produced slightly over 84% of the coal consumed to date.
- Distribution of Coal Reserves in the United States - the distribution of the coal reserves in the United States is shown by Figure 4, which gives aereal distribution and Figure 5, which quantitatively describes the total resources remaining. From an examination of Figure 5, it is apparent that coal from the following seven states would represent the vast majority of the remaining resources of bituminous coal in the United States: Illinois, W.Virginia, Colorado, Pennsylvania, Kentucky, Ohio and Indiana.

TABLE 2. COAL SELECTION

Category	State	County	Mine	Seam	1972 Production 000 tons	Company
Sub-Bituminous Coal & Lignites Western Coals	Colorado	Routt	Edna	Wadge	875	Pittsburg & Midway Coal Mining Company
	New Mexico	San Juan	Navajo	Nos6,7,8	6,898	Utah International Company
	Wyoming	Campbell	Belle Ayr	Roland-Smith	33[d]	Amax Corporation
	Montana	Rosebud	Colstrip	Rosebud	5,500	Western Energy Corporation
Bituminous Coal Western Interior Region	Iowa	Marion	Weldon	Des Moines No.1	103	Weldon Coal Company
Bituminous Coal Eastern Interior Coal Basin	Illinois	Gallatin	Eagle No.2	Illinois No.5	1,100	Peabody Coal Company
	Illinois	Jefferson	Orient No.6	Herrin No.6	1,843	Freeman Coal Mining Company
	Kentucky (West)	Union	Camp Nos.1 & 2	No. 9 Seam	2,086	Peabody Coal Company
Bituminous Coal - Appalachian Coal Basin	Maryland	Garrett	Walker	Upper Kittanning	201	Buffalo Coal Company
	Ohio	Belmont	Egypt Valley No.21	Pittsburgh No.8	4,223	Hanna Coal Company, Div. Consolidation Coal
	Kentucky (East)	Harlan	No.1	Mason	234	Dixie Fuel Company
	Pennsylvania	Armstrong	Jane	Lower Freeport	1,999	Rochester & Pittsburgh Coal Company
	Pennsylvania	Clarion	Fox	Lower Kittanning	2,036	C&K Coal Co., Subsidiary Gulf Resources Chemical Corp.
	Pennsylvania	Greene	Warwick	Sewickley	1,714	Duquesne Light Company
	West Virginia	Monongalia	Humphrey No.7	Pittsburgh	3,008	Christopher Coal Co., Div.Consolidation Coal

[d] Mine under development, projected production 6,000,000 tons/year.

TABLE 3
COAL ANALYSIS SUMMARY[a]

Mine	Seam	As Received Basis		Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Rank	Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Edna	Wadge	hvCb	8.41	0.75	0.14	0.00	0.61	9.13	40.65	50.22	12246
Navajo	Nos.6,7,8	hvCb	11.07	0.81	0.28	0.03	0.50	25.29	35.51	39.20	10050
Belle Ayr	Roland-Smith	subA	19.14	0.76	0.22	0.00	0.54	7.55	47.11	45.34	12034
Colstrip	Rosebud	subB	20.41	1.01	0.34	0.00	0.67	10.38	43.09	46.53	11591
Weldon	Des Moines No.1	hvCb	13.29	6.39	5.24	0.15	1.00	15.74	40.62	43.64	11760
Eagle No.2	Illinois No.5	hvAb	3.31	4.29	2.64	0.04	1.61	26.53	34.30	39.17	10566
Orient No.6	Herrin No.6	hvAb	3.51	1.66	1.30	0.01	0.36	22.51	31.67	45.82	11163
Camp Nos.1 and 2	Seam No.9	hvBb	3.99	4.51	2.80	0.06	1.65	21.13	35.86	43.01	11105
Walker	Upper Kittanning	lvb	2.07	0.71	0.07	0.00	0.64	16.67	18.89	64.44	12602
Egypt Valley No. 21	Pittsburgh No. 8	hvAb	2.07	6.55	5.07	0.14	1.34	25.29	36.12	38.59	10594
No. 1	Mason	hvAb	2.22	3.12	1.98	0.08	1.06	11.39	38.91	49.70	13054
Jane Nos.1 and 2	Lower Freeport	hvAb	1.17	1.85	1.44	0.00	0.41	21.75	30.07	48.18	11932
Fox	Lower Kittanning	hvAb	1.83	3.83	3.09	0.05	0.69	13.55	38.33	48.12	12973
Warwick	Sewickley	hvAb	1.50	1.37	1.09	0.01	0.27	40.47	27.77	31.76	8612
Humphrey No.7	Pittsburgh No. 8	hvAb	1.63	2.58	1.59	0.01	0.98	9.88	37.66	52.46	13631

[a] For complete set of data, see Appendix C.

PRODUCTION AND RESERVES

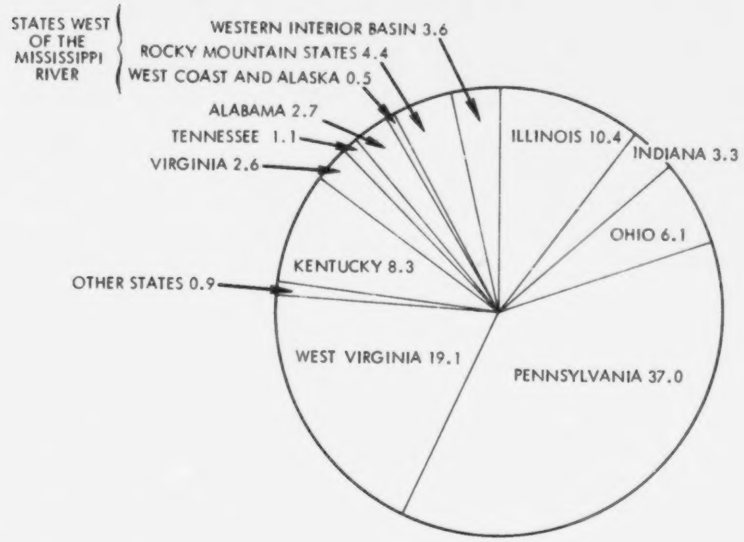
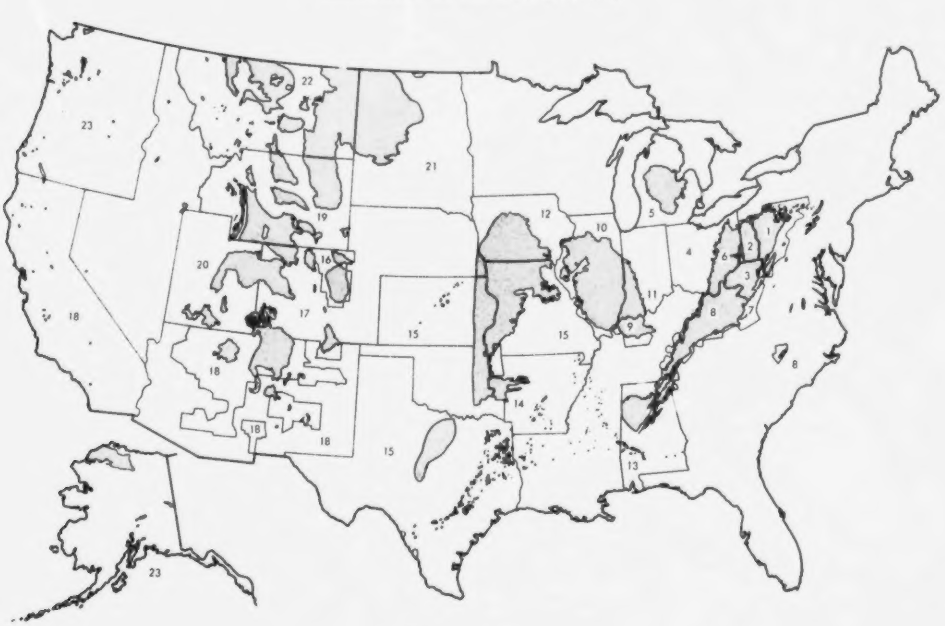


Figure 3.

Percentage Distribution of Cumulative Coal Production of the United States to 1 January 1967

COAL FIELDS OF THE UNITED STATES


23
22
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14
13

Figure 4.

Coal Fields of the Conterminous United States

- Distribution of Sulfur Content in Coal - Table 4 shows the general distribution and average sulfur content of U.S. coals. This distribution shows that the major areas containing high sulfur coal are east of the Mississippi River.

TABLE 4

AVERAGE SULFUR CONTENT OF U.S. COAL*

Coal Resources Determined by Mapping and Exploration	Low Sulfur (1.0% or Less)	Medium Sulfur (1.1-3.0%)	High Sulfur (+3%)
Total bituminous coal, subbituminous coal, and lignite	65%	15%	20%
Bituminous coal east of the Mississippi River	20%	37%	43%

*Dry basis.

A review of the average sulfur content of the states previously demonstrated to be of interest from a reserve or production point of view are listed below in Table 5.

TABLE 5

AVERAGE SULFUR CONTENT OF COALS BY STATE*

State	%S
● Colorado	0.56
● West Virginia	1.40
● Illinois	2.95
● Kentucky	2.22
● Ohio	3.52
● Indiana	3.00
● Pennsylvania	1.96

*Dry basis.

4.2.1.2 Coal Sample Selection

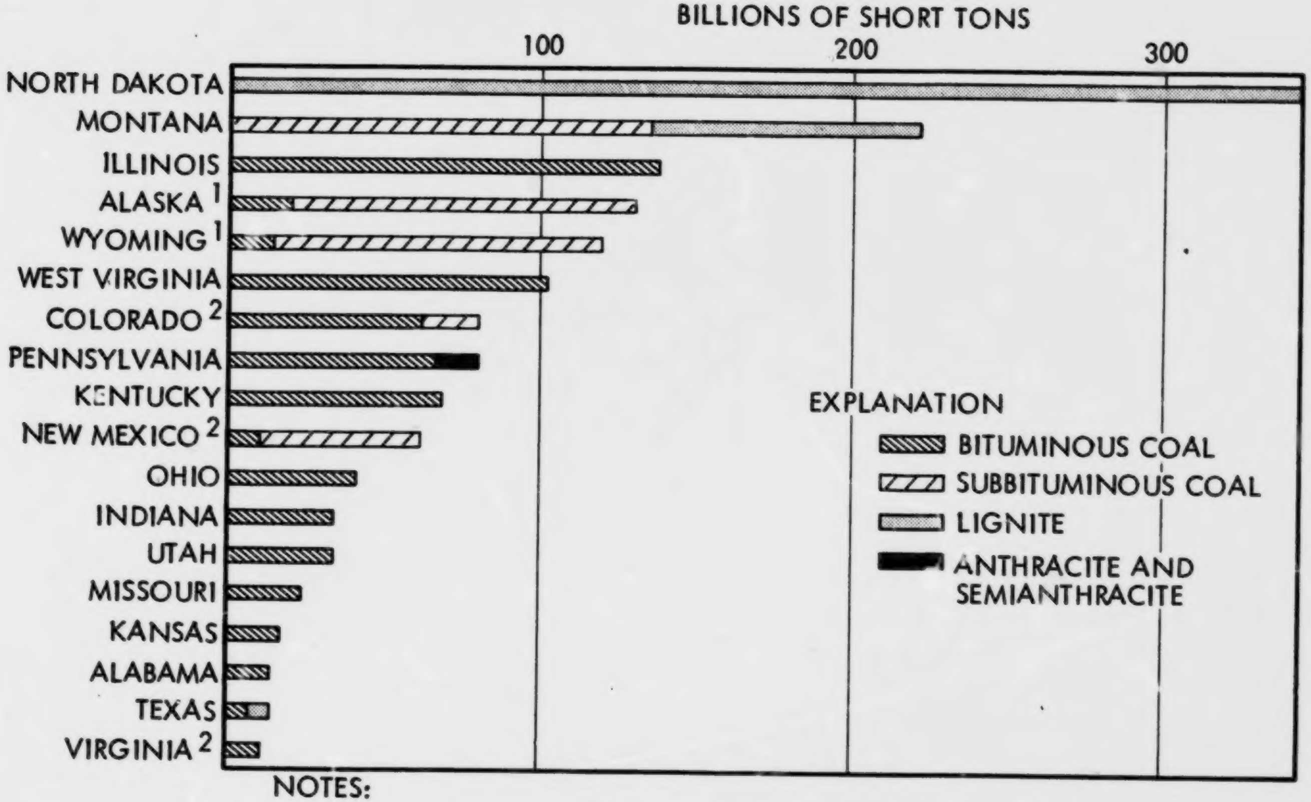
APPALACHIAN COALS

Coals sampled, as noted in the following sections, are given in their descending stratigraphic order in the Monongahela, Conemaugh, and Allegheny stratigraphic groups, as defined in Pennsylvania and correlated with other beds of the Appalachian Region.

- Sewickley Seam - the Sewickley seam, most recent in geologic age of the coal beds investigated, is present in Pennsylvania (Greene, Butler, Clarion, Armstrong, Washington, Feyette, Westmoreland and Allegheny Counties), West Virginia (Marion, Monongalia, Wetzel,

FIGURE 5.

COAL RESOURCES OF THE UNITED STATES



NOTES:

1 SMALL RESOURCES OF LIGNITE INCLUDED WITH SUBBITUMINOUS COAL
2 INCLUDES ANTHRACITE IN QUANTITIES TOO SMALL TO SHOW ON SCALE OF DIAGRAM

Marshall and Ohio Counties, where an estimated 2 billion tons remain), and Ohio, where the Sewickley correlates with the Meiggs Creek (or No. 9) seam which is found in Monroe, Belmont, Harrison and Jefferson Counties. The Meiggs Creek seam ranks third in production in Ohio. This program initiated the examination of this coal with a sample from the Warwick mine of the Duquesne Light Company in Greene County, Pennsylvania. This mine produces 2 million tons of coal per year. State maps showing the extent of this bed and location of the single sample taken to date are shown in Appendix A as Figures A-1, A-2 and A-3.

- Pittsburgh Seam - the Pittsburgh bed has been described as the most valuable individual mineral deposit in the United States. It is of minable thickness over an area of about 6,000 square miles in Pennsylvania (Washington, Greene, Indiana, Somerset, Allegheny, Armstrong, Westmoreland and Fayette Counties where approximately 7 billion tons remain), West Virginia (parts of Brooke, Ohio, Marshall, Wetzel, Monongalia, Marion, Doddridge, Harrison, Taylor, Preston, Mineral, Barbour, Upshur, Lewis, Gilmer, Braxton, Calhoun, Clay, Roane, Kanawha, Putnam, Mason, Cabell and Wayne Counties with approximately 10 billion tons of minable reserves), and eastern Ohio (primarily Belmont, Harrison, Jefferson, Carroll, Columbiana and Mahoning Counties which contain some 10 billion tons of reserve). Pittsburgh coal is also found in the Georgis Creek basin (Garrett and Allegheny Counties, Maryland) where only about 2 million tons remain. A Pittsburgh coal from Greene County, Pennsylvania was examined in the previous bench-scale program(1). This program expands the coverage of the Pittsburgh bed by sampling coals from the Egypt Valley No.21 mine of the Hanna Coal Co., Division of Consolidation Coal Co., in Belmont County, Ohio, which produces five million tons of coal a year from this strip mine, and the Humphrey No.7 mine, also of the Consolidation Coal Co., in Monongalia County, W. Virginia which produces more than three million tons per year from this deep mine. State maps showing the counties containing minable Pittsburgh coal and the locations of the mines sampled to date are shown in Figures A-4, A-5 and A-6. In this case, where the remaining reserves are rather clearly defined, the yearly production of the mines sampled represent approximately one-three thousandths of the seam reserve.

- Lower Freeport Seam - the Lower Freeport seam is also present in Pennsylvania, West Virginia, Ohio and Maryland, where it is sometimes called the No.6A coal. In Pennsylvania it is present in Lawrence, Beaver, Washington, Greene, Butler, Allegheny, Fayette, Westmoreland, Armstrong, Indiana, Somerset, Cambria, Bedford and Fulton Counties. In West Virginia, it is minable in parts of Nicholas, Roane, Braxton, Preston, Ohio, Brooke and Hancock Counties. Of the original 700 million tons minable in West Virginia, comparatively little has been removed. In Ohio the Lower Freeport is present and of importance in Jefferson, Athens, and Perry Counties where some 3 billion tons remain. In Maryland the Lower Freeport is mined in Garrett and Allegany Counties in the northwest corner of the state bordering on West Virginia and Pennsylvania. For this program, a sample was taken from the Jane Mine of the Rochester and Pittsburgh Coal Co., in Armstrong County, Pennsylvania, which produces 2 million tons per year from two deep mines. State maps showing the counties with minable Lower Freeport coal as well as the location of the mine sampled are shown in Figures A-7, A-8 and A-9. Since only two counties in Maryland are of concern, they are not mapped.

- Upper Kittanning Seam - the Upper Kittanning coal is stratigraphically the uppermost of the three Kittanning coals originally named at Kittanning, Pennsylvania. In Pennsylvania (Lawrence, Beaver, Washington, Greene, Fayette, Westmoreland, Armstrong, Clarion, Jefferson, Indiana, Somerset, Cambria and Clearfield Counties) the seam is thin and thus infrequently deep-mined. In West Virginia, the coal is of sufficient thickness for mining in parts of Kanawha, Nicholas, Clay, Braxton, Webster, Upshur, Lewis, Randoph, Barbour, Harrison, Taylor, Marion, Monongalia and Preston Counties over an area of some 1400 square miles. The original reserves in West Virginia were estimated at 4 billion tons and since this bed has not been a major producer for the state, the majority of the coal remains.

  The Upper Kittanning seam is not a major coal bed in Ohio but geologically it follows the Lower Kittanning in its persistence from northeast to southwest in the Ohio coal fields. In Maryland, the Upper Kittanning seam is mined in both Garrett and Allegany Counties where it forms parts of the 1 billion tons of remaining coal reserves.

  One sample for this program was taken from the Walker Mine of the Buffalo Coal Co., in Garrett County, Maryland, where two hundred thousand tons a year are taken by auger and strip mining. State maps showing the extent of this bed are shown in Figures A-10, A-11 and A-12. (Maryland, where the sample was taken, is again not shown because of the two county representations.)

- Lower Kittanning - the Lower Kittanning bed is most pervasive throughout the northern part of the Appalachian basin throughout portions of Pennsylvania, West Virginia, Ohio and Maryland. In Pennsylvania (Lawrence, Beaver, Washington, Greene, Fayette, Westmoreland, Butler, Clarion, Armstrong, Somerset, Indiana, Jefferson, Clearfield, Cambria, Bedford and Fulton Counties) it is widely strip mined. In West Virginia the Lower Kittanning (also called the No.5 Block) is minable in parts of Mingo, Logan, Boone, Wayne, Lincoln, Kanawha, Nicholas, Fayette, Clay, Roane, Braxton, Webster, Randolph, Upshur, Lewis, Barbour, Taylor, Marion, Monongalia, Preston and Mineral Counties. It covers an area greater than 2600 square miles and is estimated to have originally contained over 10 billion tons. Though one of the most mined beds of West Virginia much of this reserve remains. This coal is present in most of the counties comprising the coal fields of eastern Ohio, extending from Mahoning County in the northeast through Lawrence and Scioto Counties in the southeast. In Ohio, the estimated minable reserves total three billion tons. The coal is also present in the two coal counties of Maryland (unmapped) though not of major commercial importance.

The previous program examined a Lower Kittanning coal from Indiana County, Pennsylvania. During the present program, a sample was also obtained from the Fox mine of the C&K Coal Co., in Clarion County, Pennsylvania which produces two million tons per year from this strip mine. State maps showing the extent of this bed and the location of the two samples are shown as Figures A-13, A-14 and A-15.

- Mason Seam - to provide an example of an Eastern Kentucky coal, a sample was taken from the Dixie Fuel Company's No.1 mine in Harlan County, Kentucky which mines three hundred thousand tons a year from this seam. A state map showing the location of the sampling point in the Upper Cumberland reserve district is shown in Figure A-16.

EASTERN INTERIOR REGION

- No.5 Bed (Seam) - the No.5 Bed is the most widespread and commercially valuable coal bed in the Eastern Interior coal basin. It is known in Illinois as the No.5, Harrisburg or Springfield beds; in Indiana as the Springfield or No.V bed; and in western Kentucky as the No.9 bed. It is of minable thickness over an area of about 20,000 square miles in the three states and it is recognizable as a lithologic unit over an area of about 30,000 square miles. In southeastern Illinois, it is 4-5 feet thick over large areas; in Indiana it has an average thickness of 5 feet and locally is as much as 11 feet thick throughout its area of occurrence. From the standpoint of resources, it is the most important bed in Indiana and western Kentucky, and it is second only to the Herrin No.6 bed in Illinois.

  In Illinois the No.5 Bed is present in strippable quantities in some fifty counties having more than forty-one billion tons of reserves. In Indiana the Springfield (No.V) Bed is present in Sullivan, Vigo, Knox, Greene, Daviess, Pike, Gibson, Posey, Vanderburgh and Warrick Counties, which contain twenty six billion tons of reserve.

  The correlating coal seam in western Kentucky (the No.9 Bed) is commonly found throughout the entire reserve district and presently may be mined in Butler, Daviess, Henderson, Hopkins, Muhlenberg, Ohio, Union, or Webster Counties.

  The original program utilized a No.5 coal from Fulton County, Illinois, and the present program gathered samples from two Peabody Coal Company mines: the Eagle No.2 deep mine in Gallatin County, Illinois, and the Camp Nos.1 and 2 deep mines in Union County, Kentucky. These mines presently produce a total of three million tons per year. State maps showing the extent of these correlated beds are shown as Figures A-17, A-18 and A-19.

- Herrin No.6 Bed (Seam) - the Herrin No.6 bed is recognizable over an area of about 15,000 square miles in the Eastern Interior coal basin, where it is second in commercial importance only to the No.5 bed. It is known in western Kentucky as the No.11 bed and in Indiana as the Hymera or VI bed. This coal attains maximum thickness in southern Illinois, where it is locally as much as 14 feet thick. In central Illinois and in western Kentucky, the Herrin (No.6) bed is 5-7 feet thick over large areas. It thins eastward and is relatively unimportant in Indiana. It also thins toward the northwest edge of the basin. From the standpoint of resources and production, it is the most important coal in Illinois. In Illinois the No.6 bed has reserves in fifty-six counties, totalling approximately sixty-six billion tons. In Kentucky the No.11 bed is presently being mined in Hopkins, Ohio and Muhlenberg Counties. Indiana's equivalent Hymera (No.VI) bed is of lesser importance but it occurs in minable thickness in Sullivan, Knox, Pike, Gibson, Warrick, Vanderburgh and Posey Counties.

The previous bench-scale program(1) utilized a No.6 coal from Randolph County, Illinois and the present program examined a sample of No.6 coal from the Orient No.6 mine of the Freeman Coal Mining Company in Jefferson County, Illinois. State maps showing the extent of the minable beds and the location of the mine samples are shown in Figures A-20, A-21 and A-22.

WESTERN INTERIOR REGION

- Des Moines No.1 - to provide a sample of coal from the Western Interior Region, an Iowa coal from Marion County (the Des Moines No.1) seam was selected. Some one hundred thousand tons per year of this coal are mined by the Weldon Coal Company at their Weldon strip mine which is one of the largest in the state. Iowa's total reserves are an estimated 7 billion tons.

WESTERN COAL REGION

- Wadge Seam - the Wadge seam of the Yampa field in the Green River region is an example of coals from the northwestern part of Colorado. The Edna mine of of the Pittsburg and Midway Coal Mining Company in Routt County was sampled; it produces nine hundred thousand tons per year and is one of the larger mines in Colorado. The Wadge seam in Colorado correlates with other coals of the Green River Region mined in the Rock Springs area in southwestern Wyoming. In Colorado, the reserves are estimated at some one and one-half billion tons.
- No.6, 7 and 8 Seams (Fruitland Formation) - the No.6, 7 and 8 seams of the Fruitland Formation are presently being mined by one of the largest stripping operations in the nation at the Navajo mine in San Juan County, New Mexico. This mine is operated by the Utah International Company and produces over six million tons of coal per year. The coal resources of New Mexico are estimated at 62 billion tons, 80% of which are sub-bituminous coals which include the coal mined at the Navajo mine.
- Roland-Smith Seam - the Roland-Smith seam of the Powder River Region represents one of the largest strippable reserve areas of sub-bituminous coal in the U.S. For this program a sample of the seam was taken from the Belle Ayr mine in Campbell County (center of the Powder River Region) operated by the Amax Corporation.
- Rosebud Seam - the Rosebud seam of sub-bituminous coal is representative of the vast reserves (20 billion tons) of strippable coal available in the Fort Union Region of Eastern Montana. This region is represented in northeastern Wyoming by the coals of the Powder River Region and translates into the lignites of eastern Montana and western North Dakota. For the survey program, a sample was taken from a large mine in the area, the Colstrip

mine in Rosebud County, operated by the Western Energy Corporation. This mine produces five million, five hundred thousand tons of coal per year.

4.2.2 Sampling of Coals

One-ton samples of raw run-of-mine (ROM) coal were collected from each mine. The samples taken in increments that represent at least a day's production. Stopped belt samples were utilized as a first preference and falling stream intercepts as an alternative. Auger sampling of unit trains containing western coals was also utilized in cases where it could be shown that the train contained only ROM coal from a single seam and mine.

The samples were sealed in plastic-lined drums (six per mine) for shipment to Commercial Testing and Engineering Laboratory (CT&E) where each 2,000 pound gross sample was crushed to 1½" x 0 by a jaw crusher, divided into four parts and treated as follows:

- a 1½" x 0 fraction for float-sink fractionation,
- a second part was crushed to 3/8" x 0 for float-sink fractionation,
- a third part was crushed to 14 mesh x 0 for float-sink fractionation. A 25-lb sample of this material was also sent to TRW for chemical processing to remove pyritic and organic sulfur,
- the remaining part was held in reserve.

Float-sink fractionation of portions 1, 2 and 3 above was performed with organic liquids at 1.30, 1.40, 1.60 and 1.90 specific gravities. The resulting fractions were analyzed for ash, total sulfur, and pyritic sulfur on a dry basis. These results were then used to calculate washability tables to determine cumulative recoveries and rejects at the various specific gravities.

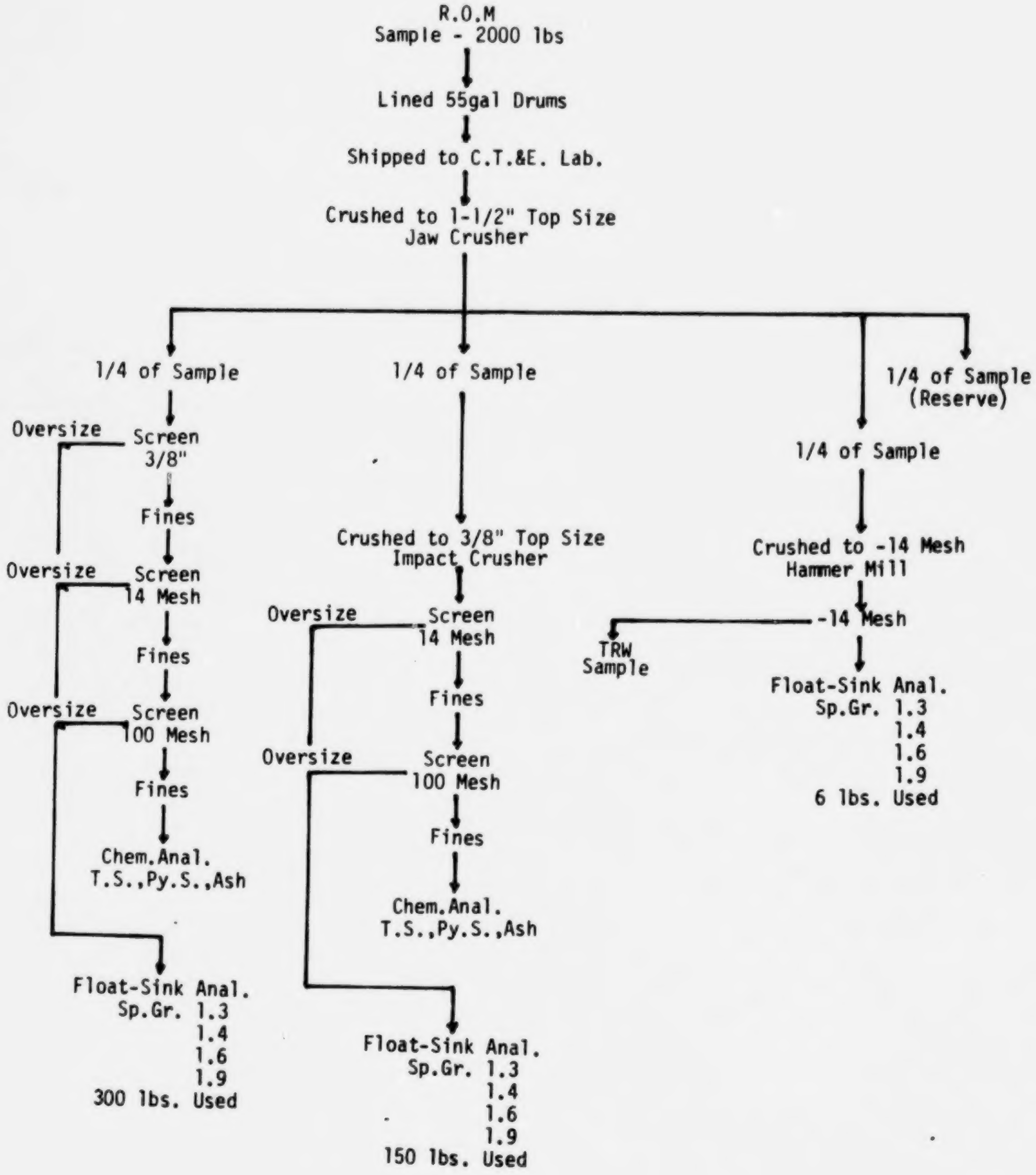
Since four coal mine samples (Edna, Navajo, Belle Ayr, and Colstrip) had such low pyritic sulfur content that float-sink fractionation for its removal appeared impractical, these samples were omitted from float-sink studies.

Figure 6 illustrates the sequence of sampling and testing.

The procedures used to collect each of the 15 1-ton samples are described below:

FIGURE 6. U.S. BUREAU OF MINES SAMPLING, HANDLING SYSTEM

AMENDED


R.O.M
Sample - 2000 lbs
Lined 55gal Drums
Shipped to C.T.&E. Lab.
Crushed to 1-1/2" Top Size
Jaw Crusher
1/4 of Sample
1/4 of Sample
1/4 of Sample
(Reserve)
Oversize
Screen
3/8"
Fines
Oversize
Screen
14 Mesh
Fines
Oversize
Screen
100 Mesh
Fines
Chem.Anal.
T.S.,Py.S.,Ash
Float-Sink Anal.
Sp.Gr. 1.3
1.4
1.6
1.9
300 lbs. Used
Crushed to 3/8" Top Size
Impact Crusher
Oversize
Screen
14 Mesh
Fines
Oversize
Screen
100 Mesh
Fines
Chem.Anal.
T.S.,Py.S.,Ash
Float-Sink Anal.
Sp.Gr. 1.3
1.4
1.6
1.9
150 lbs. Used
1/4 of Sample
Crushed to -14 Mesh
Hammer Mill
-14 Mesh
TRW
Sample
Float-Sink Anal.
Sp.Gr. 1.3
1.4
1.6
1.9
6 lbs. Used

- Edna Mine, Wadge Seam, Routt County, Colorado, Pittsburg and Midway Coal Mining Co. The raw run-of-the-mine coal crushed to 3" x 0 was collected on April 10, 1973,at 10-minute intervals by cutting a stream at the discharge chute throughout a three and a half hour period.

- Navajo Mine, Blended Seams 6,7,8, San Juan County, New Mexico, Utah International Co. The raw run-of-the-mine coal was collected by taking stopped belt increments at 10-minute intervals throughout a 3-1/2 hour period on April 12, 1973, from the No.7 blend pile. The raw coal had been blended in the pile to represent proportional portions of Seams 6, 7 and 8 as produced by this mine.

- Belle Ayr Mine, Roland-Smith Seam, Campbell County, Wyoming, Amax Corporation. The raw run-of-the-mine sample crushed to 2 x 0" was collected throughout a 24-hour period on February 13, 1973, as 10,000 tons of Belle Ayr coal was transferred to barges at East St.Louis, Illinois. Stopped belt increments were taken at 10-minute intervals throughout the entire transfer operation.

- Colstrip Mine, Rosebud Seam, Rosebud County, Montana, Western Energy Corporation. The raw run-of-the-mine sample crushed to 1½" x 0 was collected on March 31, 1973, at the Commonwealth Edison State Line Plant, Hammond, Indiana, from 10,000 ton unit train No.CS-3. Thirty pound increments were taken from each car of the 100-car unit train by means of a truck mounted coal auger driven to a depth of 8 feet.

- Weldon Mine, Des Moines Seam No.1, Marion County, Iowa, Weldon Coal Company. The raw run-of-the-mine sample crushed to 2" x 0 was taken on April 4, 1973, by removing fifteen 16-lbs increments form each of 9 cars (135 increments total) as loaded by the Weldon Coal Company.

- Eagle Mine No.2, Illinois No.5 Seam, Gallatin County, Illinois, Peabody Coal Company. The raw run-of-the-mine sample was collected over a 5-hour period on January 29, 1973, at Eagle No.2 mine in Gallatin County, Illinois. Sixty increments of approximately 35 lbs each were taken from the stopped belt leading from the raw coal silo.

- Orient No.6 Mine, Herrin No.6 Seam, Jefferson County, Illinois, Freeman Coal Mining Corp. The raw run-of-the-mine sample was collected on January 31, 1973, at the Orient No.6 mine in Jefferson County, Illinois. A 1-ton gross sample was collected in 55-lbs increments taken every 10 minutes over a 6-hour period from the automatic sampler on the raw coal belt.

- Camp Mine 1 & 2, No.9 Seam, Union County, Kentucky, Peabody Coal Company. The raw run-of-the-mine coal was collected throughout a 4-hour period on January 30, 1973. The raw coal from the two Camp mines is blended in a silo prior to the automatic sampler. Forty-eight increments were collected by the secondary cutter of the automatic sampler at 5-minute intervals.

- Walker Mine, Upper Kittanning Seam, Garrett County, Maryland, Buffalo Coal Co. The raw run-of-the-mine sample was collected over a 4-hour period on March 7, 1973. Sixty increments were collected from 15 locations in the raw coal pit.

- Egypt Valley No.21 Mine, Pittsburgh No.8 Seam, Belmont County, Ohio, Hanna Coal Co. On March 5, 1973, a raw run-of-the-mine sample was obtained over a 4-1/2-hour period. This sample was taken in four 35-40 lb increments at each of fifteen locations in the raw coal.

- No.1 Mine, Mason Seam, Harlan County, Kentucky, Dixie Fuel Co. The raw run-of-the-mine sample was collected over a 5-hour period on March 28, 1973. Increments of approximately 150 lbs each were collected at 8-minute intervals. The gross 6000 lb sample was then reduced in size by the cone and quartering method to 2276 lbs.

- Jane Mine, Lower Freeport Seam, Armstrong County, Pennsylvania, Rochester & Pittsburgh Coal Co. The raw run-of-the-mine sample crushed to 1-1/2" was collected throughout a 4-hour period on March 8, 1973. One hundred and eighty increments were taken from the raw coal belt leading from the crusher. Stop-belt sampling was employed throughout the sampling period.

- Fox Mine, Lower Kittanning Seam, Clarion County, Pennsylvania, C&K Coal Co. The raw run-of-the-mine sample was collected over a 4-1/2 hour period on March 8, 1973. From 15 locations in the raw coal pit, 4 increments of 40 lbs each were taken from each location.

- Warwick Mine, Sewickley Seam, Greene County, Pennsylvania, Duquesne Light Company. The raw run-of-the-mine sample was collected throughout four, 3-1/2 hour periods on March 5, 1973. Increments were taken from the No.1 stopped belt at 5 minute intervals. A total of forty increments, each weighing about 50 lbs, was taken.

- Humphrey No.7 Mine, Pittsburgh No.8 Seam, Monongalia County, West Virginia, Consolidation Coal Company. The raw run-of-the-mine coal was collected over a 3 hour and 20 minute period on March 6, 1973. The Pittsburgh No.8 Seam was sampled at the automatic sampler on No.1 belt going from the mine to the cleaning plant. Forty increments of approximately 55 lbs each were collected after the primary sampler by stopping the feed belt to the secondary sampler crusher and cleaning the belt.

4.2.3 Coal and Sample Preparation at TRW

A 25-lb (11.4 kg) sample of coal ground to 14 mesh x 0 was shipped from CT&E to TRW in a sealed polyethylene bag inside a 5-gallon can. If any surface moisture was observed, the coal was spread on a polyethylene sheet in a fume hood and allowed to air dry from 4 to 6 hours. This gross sample was then reduced by riffling into two 1600-2000g portions. One sample was stored under nitrogen or argon in a glass container as a reserve, and the other was ground in a disintegrator with a 0.58 mm screen. After several passes, the entire lot was sieved using a 100-mesh screen. All oversize material was then passed through the grinder several more times and re-sieved; this process was repeated until more than 99% of the material passed through a 100-mesh screen. The remaining 1% or less, which was slate and other rock-like material, was discarded.

The entire lot of 100 mesh x 0 coal was then thoroughly mixed by conventional cone and quartering techniques on a polyethylene sheet. The coal was then bottled as 100.0g samples in containers that had been flushed with nitrogen or argon. In order to guarantee relatively uniform samples, the coal was periodically mixed during this process.

The sieve analysis is summarized in Table 6 while complete data is presented in Appendix G. Note that while the coal is 100% 100 x 0 mesh, in most cases 91% will pass a 150 mesh screen and 70% will pass a 200 mesh screen.

TABLE 6.
SIEVE ANALYSIS OF COALS GROUND TO 100 MESH X 0[a]

MINE	SEAM	% W/W PASSING SIEVE (U.S. STANDARD MESH)					
		+100[b]	100	115	150	200	325
Edna	Wadge	0.0	100.0	99.4	96.4	80.6	12.8
Navajo	No. 6, 7, 8	0.0	100.0	98.1	91.9	69.5	7.6
Belle Ayr	Roland-Smith	0.4	99.6	91.6	82.0	59.8	7.4
Colstrip	Rosebud	0.2	99.8	95.1	86.3	61.4	5.0
Weldon	Des Moines No. 1	0.0	100.0	96.6	91.8	76.0	3.2
Eagle No. 2	Illinois No. 5	0.2	99.8	96.8	91.4	75.2	7.6
Orient No. 6	Herrin No. 6	0.2	99.8	94.2	86.4	67.5	6.8
Camp Nos.1 & 2	No. 9	0.8	99.2	95.6	88.6	67.9	7.0
Walker	Upper Kittanning	0.0	100.0	97.7	92.7	73.4	3.2
Egypt Valley No. 21	Pittsburgh No. 8	0.0	100.0	98.6	95.2	75.0	3.1
No. 1	Mason	0.0	100.0	97.2	91.4	71.4	7.5
Jane	Lower Freeport	0.2	99.8	94.2	85.8	63.8	2.8
Fox	Lower Kittanning	0.0	100.0	98.9	94.1	60.5	3.4
Warwick	Sewickley	0.1	99.9	97.2	91.1	74.1	4.8
Humphrey No. 7	Pittsburgh	0.0	100.0	98.8	92.3	67.3	3.7
	Median	0.0	100.0	97.2	91.4	69.5	5.0

[a] Complete data in Appendix G.

[b] Retained on 100 mesh sieve.

4.3 CHEMICAL REMOVAL OF PYRITIC SULFUR

This section presents descriptions of the experimental methods and summarizes results from the studies involving chemical removal of pyritic sulfur from the surveyed coals. The removal of trace elements from coals as a result of the Meyers Process is described in Section 4.6 together with a discussion of the experimental methods used to determine the trace element composition. One coal of the fifteen sampled, the Walker, contained too little pyritic sulfur to be included in the chemical removal studies (<0.1% w/w). Because of this and the need to relate current program results to previous experimentation, the Lower Kittanning seam coal utilized in the bench scale program(1) was substituted for the Walker coal. Also included in this section are discussions of (a) pyritic sulfur removal, (b) ferric ion consumption and its relationship to the final heat content of coal, (c) ash changes, (d) sulfate retention, (e) changes in the organic sulfur content and (f) miscellaneous findings.

4.3.1 Experimental Method

The general conditions for pyritic sulfur removal have been adapted from the previous bench scale studies (EHSD 71-7)(1) with the objective of obtaining maximum pyritic sulfur removal and of simulating process design as nearly as possible. A check-out run with Lower Kittanning coal was performed to establish baseline extraction values.

Mesh Size - Coal ground to 100 mesh x 0 or finer has been found to give the maximum extraction rates and to be most satisfactory for laboratory scale sampling.

Ferric Ion Concentration - Ferric sulfate solution 1N in ferric ion appears to be optimum, although differences due to concentration change do not appear to be great.

Reaction Temperature - The reaction temperature was held at the reflux of a 1N ferric sulfate solution which is approximately 102°C. This allows a reasonably high reaction rate and yet does not require pressure equipment.

A trial experiment was run for each coal (due to the high variance in the behavior of individual coals) in order to select the reaction time, leach solution to coal weight ratio, and number of leach solution changes needed for maximum removal.

Reaction Time - Each coal was leached a total of ten or more hours depending on the characteristics of the individual coal treated.

Ferric Ion to Total Iron Ratio - Since the rate of pyrite removal is slowed substantially by ferrous ion accumulation, each coal was treated under conditions designed to keep this ratio >0.80 by one of the following means:

- Increasing the leach solution to coal ratio (v/w) from a nominal 10 to a maximum of 40
- Changing the leach solution after 3-6 hours of reaction or more often if required
- A combination of the above.

Post Sample Treatment - After treatment the samples were thoroughly washed to remove any residual leach solution and then dried. All sample calculations were done on a dry basis in order to eliminate variables due to wetness of the coal. Sulfur forms and proximate analysis have been obtained for each treated coal sample.

4.3.1.1 Extraction Procedure - The exact procedure used in this survey is described below:

> One hundred grams of 100 mesh x 0 coal are added to 2 ℓ refluxing 1N ferric sulfate solution contained in a 4-neck, 3 ℓ glass cylindrical reaction vessel equipped with a mechanical stirrer, reflux condenser, and a thermocouple attached to a recorder. Each vessel also has a stopcock at the bottom for taking samples and is heated by a specially constructed heating mantle. After the coal addition, an additional 0.5 ℓ of 1N ferric sulfate solution is used to wash down the sides of the vessel. At this point, the initial solution sample is taken and the leaching process is considered started. Then, the reaction mixture, which is at 88±4°C, is rapidly brought to reflux, a process that takes 8-12 minutes. Leach solution samples for each analysis are taken by drawing a 200 ml aliquot of the reaction mixture from which a 20 ml sample is taken and cooled immediately to 0°C. Unused material is returned to the reaction flask. After cooling, a 14 ml aliquot is centrifuged to removal all suspended solids and 10 ml of this is used for iron analysis. Any remaining coal or leach solution is returned to the reaction flask.

After 4-6 hours, the heating is stopped and the reaction mixture is drained from the flask and vacuum filtered as dry as possible to produce a dewatered product. The final reaction volume and approximate solution retention on the coal are then determined. The unwashed coal is then slurried with 200 ml fresh ferric sulfate solution at 30°C and added to 2 ℓ fresh 1N ferric sulfate solution at reflux. Another 300 ml ferric sulfate is then used to wash any residual coal into the flask. An initial leach solution sample is then taken and the entire reaction mixture is brought to reflux in 8-12 minutes. Leach solution samples are taken at regular intervals and, after a total elapsed reaction time of 10 to 24 hours, the reaction mixture is drained from the reaction flask, filtered, and washed with 0.5-1.0 ℓ water.

The extracted coal is then slurried with 2 ℓ of 1N sulfuric acid at ~80°C for 2 hours, filtered, and stirred with another 2 ℓ 1N sulfuric acid at ~80°C for an additional two hours. After filtration, this procedure is repeated with 2 ℓ water at ~80°C. If scheduling does not permit coal to be extracted with toluene immediately, it is stirred at ~50°C for an extended period until it can be filtered and extracted with toluene for removal of free sulfur formed during the leaching operation.

After the extraction of residual sulfate and iron by the above washing procedure, the wet coal is transferred into a 1 ℓ round bottom flask equipped with a mechanical stirrer and Dean-Stark trap. A 400 ml volume of toluene is added and the mixture is brought to reflux. This is continued for 15 minutes beyond the point when all the water has been removed by azeotropic distillation (approximately 0.75-1.25 hr and 50-75 ml). The hot coal slurry is then filtered, washed with 50-75 ml toluene and dried in a vacuum oven at 100-120 C. The coal is then weighed and analyzed.

4.3.1.2 Sulfur Forms Analysis - The procedure for sulfur forms analysis is described in ASTM Standard D2492 and consists of extraction of sulfate sulfur along with non-pyritic iron with 5N HCl. Sulfate is determined by precipitation of $BaSO_4$ with $BaCl_2$ after removal of iron from the solution. This is followed by a 2N nitric acid extraction to remove pyritic sulfur. The nitric acid extraction is performed on either the extracted sample or a fresh sample. Pyritic sulfur is always determined by the titration of the iron associated with the pyritic sulfur because nitric acid usually removes a small amount of organic sulfur. If a fresh sample of coal is used for nitric acid extraction, a blank iron determination must be made on the HCl extraction solution because all iron is extracted by nitric acid. Even though the two sample method involves more work, it is used most often because it allows simultaneous determination of sulfate and pyritic sulfur, and, in general, the sample size necessary for the sulfate sulfur determination creates problems for pyritic sulfur determination and *vice versa*.. The schematic of the analysis is given in Figure 7.

Coal, 5g $\xrightarrow[\text{reflux 30 min.}]{\text{5N HCl}}$ a) sulfate as $BaSO_4 \longrightarrow$ % w/w sulfate sulfur

b) non-pyritic iron as mg/g.

Coal, 1g $\xrightarrow[\text{reflux 30 min.}]{\text{2N } HNO_3}$ a) total iron as mg/g

b) mg pyritic iron/g = mg total Fe/g - mg non-pyritic Fe/g.

c) calculation of % w/w pyritic sulfur.

or

Coal, 5g $\xrightarrow[\text{reflux 30 min.}]{\text{5N HCl}}$ sulfate as $BaSO_4$ $\xrightarrow[\text{reflux 30 min.}]{\text{2N } HNO_3}$ pyritic iron $\rightarrow$ % w/w pyritic sulfur

Figure 7. Sulfur Forms Analysis Scheme

In the pyritic sulfur iron determination which is performed by converting all the iron to the ferrous form and then oxidizing it back to the ferric form with potassium dichromate, there are several possible sources of error. These are listed below:

- Color extracted by the nitric acid is often similar to the ferric ion in color and if not removed completely, interferes in the step where all the iron is reduced to the ferrous form. Addition of excess reducing agent at this point causes a poor final end point.
- Organic matter extracted by nitric acid, if not removed, is attacked by potassium dichromate, causing a diffuse and fading end point.
- Even under the best conditions, the indicator that is used has an end point that has a tendency to fade.

The ASTM standards for precision are listed in Table 7 and show that while the same operator can be expected to attain the same repeatability as the standard Eschka (total) sulfur analysis, the matter of judgment involved results in a much lower reproducibility between laboratories. In practice, the standards for the Eschka analysis can be met by almost any analyst, while those for pyritic sulfur can only be met with difficulty by an experienced analyst. Note that in this context the organic sulfur value is the sum of all these errors and, thus, is a very sensitive error indicator.

TABLE 7

SULFUR FORMS ANALYSIS - ASTM STANDARDS FOR DUPLICATE ANALYSES

MAXIMUM PERMISSIBLE SPREAD[a]							
Total Sulfur Laboratory		Pyritic Sulfur Laboratory		Sulfate Sulfur Laboratory		Organic[c] Sulfur Laboratory	
Same[b]	Different	Same	Different	Same	Different	Same	Different
Below 2%							
.05	.10	.05	.30	.02	.04	.12	.44
Over 2%							
.10	.20	.10	.40	na		.22	.64

[a] All values are % w/w sulfur.

[b] Same operator using the same equipment on the same day.

[c] Sum of all errors, not an ASTM standard.

Coal samples from the same mine analyzed before and after treatment fall into a special category. The subjective conditions under which these analyses are run can be quite different and probably would be intermediate between those assumed for replicate analyses on the same sample done in the same or different laboratories. In addition, two sets of samples are being analyzed and the maximum permissible Δ % for any form could be double that for a single set of samples. Although this is not a rigorous statistical analysis, it should be noted that the ASTM procedures as set up allow for considerable variation for Δ % organic sulfur values and, when this does occur, caution should be used in interpreting the results.

A further difficulty occurs when very low (0.00-0.15% w/w) pyritic sulfur values are encountered. In these cases, the blanks and other corrections may even exceed the actual titration volume, and the presence of only slight amounts of organic matter introduces substantial relative error into the determination.

4.3.2 Pyritic Sulfur Removal Results

Table 8 summarizes the results of the pyritic sulfur removal experiments. The percentage removal may be calculated by dividing the difference between the initial and final weight percent pyritic sulfur by the initial weight percent pyritic sulfur. However, because of the ash (both pyritic and excess) that is removed, the remaining pyritic sulfur in the treated coal is slightly concentrated and analysis on a weight basis to calculate percent removal results in a value lower than is actually the case. For this reason, a corrected value was also calculated which compares the weight of the pyrite in the treated coal to the weight of pyrite in the untreated coal. The latter value, though harder to calculate because it requires a material balance, is more nearly accurate than the former; consequently, this value will be used in the following discussions.

The results of the pyritic sulfur removal are very encouraging in that with the exception of the very low pyrite western coals, 89-99% w/w pyritic sulfur removal was achieved for all the coals treated. The low initial pyritic sulfur content of the western coals limited pyritic sulfur analysis accuracy to an extent which obscured the percentage removal calculations. For this reason calculated removals of only 59-89% were obtained even though the pyritic sulfur levels in the treated coals were reduced to a measured 0.03-0.06% w/w.

The standard set of reaction conditions utilized a reaction time of 23 hours, one change of leach solution during the 4 to 6 hour time period, and 100 mesh x 0 coal. Although high removal was achieved with the Belle Ayr and Colstrip coals using a reaction time of only 13 hours, these conditions were not sufficient for high removal from the Weldon, Orient No.6, Camp Nos.1&2 and Egypt Valley No.21 coals. Samples of these coals were ground to 200 mesh x 0 to expose more finely divided pyrite encapsulated in the coal and at the same time allow faster extraction, since the particles would be ground to smaller size and thus present a greater surface area for reaction. The 200 mesh x 0 Camp Nos. 1 & 2 coal was run for 23 hours (Run No.5) which resulted in 99% pyrite removal compared to 80-89% removal (Run Nos. 1-4) for 100 mesh x 0 coal. The remaining pyrite was reduced from 0.62% to 0.02% w/w. Since Run No.5 indicated a much increased rate of removal

TABLE 8

SUMMARY OF PYRITIC SULFUR REMOVAL DATA[a]

Mine	Seam	Rank	Run Number	Total Rxn Time	Leach Changes	Mesh[b]	Dry Basis Pyrite Analysis, % w/w			Pyrite Removal, % w/w		
							Initial	Final	Removed	Nominal[c]	Corrected[d]	Std. Dev.
Edna	Wadge	hvCb	1-3	23	1	100	0.14 ± .015	0.06 ± .020	0.08 ± .025	57	59	15
Navajo	Nos. 6, 7, 8	hvCb	1-3	23	2	100	0.28 ± .044	0.04 ± .040	0.24 ± .059	86	87	14
Belle Ayr	Roland-Smith	subA	1-3	6-10[e]	1	100	0.22 ± .017	0.03 ± .012	0.19 ± .021	86	89	5.6
Colstrip	Rosebud	subA	1-3	12-13[e]	1-2	100	0.34 ± .015	0.06 ± .006	0.28 ± .016	82	83	1.9
Weldon	Des Moines No. 1	hvCb	1-3	23	2	100	5.24 ± .038	0.47 ± .099	4.77 ± .106	91	92	1.9
			4	13	1	200		0.15	5.19	97	98	-
Eagle No. 2	Illinois No. 5	hvAb	1	13	2	100	2.64 ± .154	0.36	2.28	86	94	-
			2	14	1	100		0.11	2.53	96	98	-
			3	14	1	100		0.33	2.31	88	94	-
			4	23	1	100		0.19	2.45	93	94	-
Orient No. 6	Herrin No. 6	hvAb	1-3	23	1	100	1.30 ± .084	0.32 ± .076	0.98 ± .113	75	76	6.1
			4	23	1	200		0.12	1.18	91	92	-
			5	13	1	200		0.06	1.24	95	96	-
Camp Nos. 1 and 2	No. 9	hvAb	1-3	13	1	100	2.80 ± .120	0.62 ± .210	2.18 ± .242	78	80	7.6
			4	23	1	100		0.33	2.47	88	89	-
			5	23	2	200		0.02	2.78	99	99	-
			6	13	1	200		0.14	2.66	95	96	-
Egypt Valley No. 21	Pittsburgh No. 8	hvAb	1-3	13-22[e]	1	100	5.07 ± .025	0.62 ± .178	4.45 ± .180	88	89	3.5
			4	13	1	200		0.38	4.69	93	93	-
No. 1 (Dixie Fuel)	Mason	hvAb	1-3	23	1	100	1.98 ± .062	0.21 ± .045	1.77 ± .077	89	90	2.3
Jane	Lower Freeport	hvAb	1-2	11-23[e]	1	100	1.44 ± .098	0.14 ± .007	1.30 ± .098	90	91	0.8
			3	23	1	100		0.63	0.81	56	60	-
Fox	Lower Kittanning	hvAb	1-3	23	1	100	3.09 ± .017	0.37 ± .163	2.72 ± .164	88	89	5.3
			4	13	1	200		0.47	2.62	85	85	-
Warwick	Sewickley	hvAb	1-3	23	1	100	1.09 ± .086	0.09 ± .043	1.00 ± .096	92	92	4.0
			4	13	1	100		0.06	1.03	94	95	-
Humphrey No. 7	Pittsburgh	hvAb	1-3	23	1	100	1.59 ± .114	0.14 ± .055	1.45 ± .127	91	91	3.5
(Greene Co.)[f]	Lower Kittanning	mvb	1-3	12	1	100	3.58 ± .080	0.38 ± .089	3.20 ± .120	89	90	2.5

[a] Walker mine omitted due to low pyritic sulfur content (0.07%).

[b] 100 mesh x 0 and 200 mesh x 0 coal is symbolized as 100 and 200, respectively.

[c] This value is calculated by dividing the pyritic sulfur loss in % w/w by the initial % w/w pyritic sulfur.

[d] This value is calculated by dividing the number of milli moles of sulfur loss by the initial number of milli moles of pyritic sulfur.

[e] Indicates different reaction times with no significant difference in results.

[f] Lower Kittanning coal from previous bench-scale program(1).

an additional experiment (Run No. 6) was performed with a total reaction time of 13 hours. This run resulted in 96% pyrite removal with a final pyrite content of 0.14% w/w. Another set of experiments, using 200 mesh x 0 Orient No. 6 (Run Nos. 4-5) coal, gave much better removals than obtained with -100 mesh coal. In the 23-hour run, the removal was increased from 76% to 92%, and the final pyrite content was reduced from 0.32% to 0.12% w/w. Reducing the reaction time to 13 hours gave an apparent increase in removal to 96% with a final pyrite content of 0.06% w/w. Because the above results are from single experiments, the detailed results should be used with caution, although the general observations provide valid trends.

A series of 13-hour runs using 200 mesh x 0 coal was also conducted on the Egypt Valley No. 21, Fox, Warwick, and Weldon coals. This resulted in increased pyrite removal from 89 to 93% for the Egypt Valley coal; 92 to 95% for the Warwick coal; 92 to 98% for the Weldon coal; and a reduction from 89 to 85% for the Fox coal. The corresponding final pyrite changes were 0.62% to 0.38%, 0.09% to 0.06%, 0.47% to 0.15%, and 0.37% to 0.47%, respectively. Thus, grinding the coals to 200 mesh x 0 allows a much faster rate of reaction and equal or increased pyrite removal is observed in all but one case. Further work is necessary in order to determine whether this is general for all coals.

Although the precision of the results of this survey has been excellent, Run No. 2 on the Eagle No. 2 coal and Run No. 3 on the Jane coal are anomalous as the former shows lower than expected final pyrite and the latter shows higher than expected final pyrite. The data and circumstances surrounding these experiments have been examined and checked and no systematic reasons can be found for these discrepancies. Similarly, the high standard deviation for Runs 1 to 3 on the Camp Nos. 1 and 2 coal led to the discovery that the temperature controllers were maintaining all the leach solutions 2-6°C below reflux and that the spread in removals appeared to parallel these differences. Run No. 4, carefully held at reflux, resulted in much higher removal. A close examination of the results in Appendices C and D also shows that the spread between triplicate pyritic sulfur value is often of the order of 0.2-0.3% w/w. Thus duplicate or triplicate runs or determinations are necessary in order to get results that can be treated with a relatively high degree of confidence .

4.3.3 Heat Content Changes and Ferric Ion Consumption

Table 9 summarizes the effect of chemical extraction of pyritic sulfur from coals with ferric sulfate solutions on the heat content of the coals and how this effect is related to excess ferric ion consumption over that needed for pyrite removal. Because pyrite removal is in effect the removal of low btu "ash" (2995 btu/lb), its removal in most cases has more than compensated for any oxidation of the coal matrix. Thus, with the exception of the Western coals and one Interior Basin coal, heat content increases of 1.5-8.9% were observed. The Western coals,with low initial pyrite (0.14-0.34% w/w) and a high order of reactivity with ferric ion, had heat content decreases of 0.1-4.3%.

Although dry btu determinations are useful for those interested in shipping and using coal, a true picture of the effect of ferric ion oxidation of the organic coal matrix and its relationship to excess ferric ion consumption can only be obtained by examining the dry mineral matter free heat contents that have been corrected to eliminate any contributions to the heat content by pyrite. These values (also listed in Table 9) show a heat content loss of 2.9-8.3% for the Western coals, a +0.4 to -5.1% change for the Eastern and Western Interior Basin coals, and a +2.6 to -4.6% change for the Appalachian Basin coals. Since, theoretically, heat content gains are not possible, any gains must be attributed to inaccuracies in experimental determinations and assumptions inherent in the equation used to calculate these values. Thus, close examination of these differences, in view of experimental uncertainties and calculation assumptions, indicates that with the exception of the Orient No. 6 mine, the No. 1 mine (Dixie Fuel) and the Western coals, the reaction of ferric ion with the organic matrix has such a small effect on the heat content of the coal that the differences may not be statistically significant.

The extent of reaction of the ferric ion with the organic coal matrix is illustrated by examining excess ferric ion consumption. This value was calculated by subtracting from the total ferrous ion produced the amount of ferrous ion that should have been produced by pyrite removal, assuming the reaction chemistry of Figure 1 and dividing by the dry mineral matter

TABLE 9

SUMMARY OF HEAT CONTENT CHANGES AND EXCESS FERRIC ION CONSUMPTION[a]

Coal Mine	Seam	Dry Basis, btu/lb				Dry Mineral Matter Free Basis, btu/lb[b]				mM Excess Ferric Ion	mM/g Excess Ferric Ion	Total Fe^{++} Expt.[c] / Total Fe^{++} Calc.
		Initial	Final	Changes btu/lb	Changes % w/w	Initial	Final	Changes btu/lb	Changes % w/w			
Edna	Wadge	12246	12201	-45	-0.4	13468	13084	-384	-2.9	515	5.33	---[d]
Navajo	Nos. 6, 7, 8	10050	10035	-15	-0.1	13431	12633	-798	-5.9	959	10.79	---[d]
Belle Ayr	Roland-Smith	12034	11520	-514	-4.3	13003	11920	-1083	-8.3	974	12.04	---[d]
Colstrip	Rosebud	11591	11321	-270	-2.3	12912	11935	-977	-7.6	1520	19.09	---[d]
Weldon	Des Moines No. 1	11760	12493	+733	+6.2	13608	13323	-285	-2.1	981	11.31	---[d]
			12735[e]	+975	+8.3		13530	- 78	- .6	396	4.57	1.56
Eagle No. 2	Illinois No. 5	10566	11401	+835	+7.9	14180	14197	+ 17	+ .1	177	1.83	2.48
Orient No. 6	Herrin No. 6	11163	11034	-129	-1.2	14312	13575	-737	-5.1	478	4.77	1.47
Camp Nos.1 & 2	No. 9 (W. Ky.)	11103	11740	+635	+5.7	13841	13891	+ 50	+ .4	116	1.20	4.03
Egypt Valley No. 21	Pittsburgh No. 8	10594	11506	+912	+8.6	13800	14134	+334	+2.4	86	.88	1.34
			11533[e]	+939	+8.9		14158	+358	+2.6	121	1.23	1.13
No. 1 (Dixie Fuel)	Mason	13054	13341	+287	+2.2	14607	13938	-669	-4.6	165	1.69	1.16
Jane	Lower Freeport	11932	12392	+460	+3.9	15143	15158	+ 15	+0.1	61	0.62	1.60
Fox	Lower Kittanning	12973	13174	+201	+1.5	14809	14577	-232	-1.6	76	0.77	1.30
			13325[e]	+352	+2.7		14729	- 80	-0.5	321	3.27	1.18
Warwick	Sewickley	8612	9365	+753	+8.7	14352	14471	+119	+0.8	134	1.36	1.75
Humphrey No. 7	Pittsburgh	13631	13949	+318	+2.3	15027	14986	- 41	-0.3	98	1.00	1.85
												1.43

[a] These values are the averages of runs 1-3, except where noted.

[b] This value also has contributions to heat content by pyrite removed.

[c] The calculated value is based on a sulfate: sulfur ratio of 1.5.

[d] These values have not been calculated because the low initial pyrite makes them meaningless.

[e] 200 mesh x 0 coal; run 4 in appendix.

free organic material. These calculations show that the coals fall into three distinct classes, with the Appalachian Coal Basin coal consuming 0.62-1.69mM/g excess ferric ion, the Interior Coal Basin coal 1.20-4.77mM/g excess ferric ion and the Western coals 5.33-19.09mM/g excess ferric ion. (Use of 200 mesh x 0 coal seems to increase ferric ion consumption.) In general, these results follow the degree of metamorphism of these coals. The Western coals have low rank and an open pore structure which provides an abundance of active sites for reaction. The Eastern Interior Basin coals have a higher rank but still have an open pore structure that allows substantial reaction, while the Appalachian Basin coals, through of similar rank, have the most closed pore structure and as a result show very little reaction with the ferric ion.

4.3.4 Removal of Residual Sulfate

After extraction of pyritic sulfur substantial sulfate was retained on some coals when a minimal coal wash procedure was used. This wash consisted of three 500 ml hot water rinses of the coal on the filter funnel after filtration of the reaction mixture. This procedure, which was used on all trial runs and the final triplicate runs for Camp Nos.1&2 and Orient No.6 coals, resulted in sulfate values (sulfur as sulfate, but referred to only as sulfate in the following discussion) ranging from a very acceptable 0.06% w/w (Colstrip and Jane) to a very high 0.45-0.85% w/w (Edna, Belle Ayr, Orient No.6 and Eagle No.2) with the majority of coals falling in the range of 0.2-0.4% w/w (see Table 10).

It is currently believed that sulfate retained on the treated coals can be reduced or eliminated by one or more of the following methods: (a) control of acidity and iron concentration or form during extraction, (b) selection of optimum filtration temperature, (c) equilibration of the leach solution with the coal as in the thickener section of a process plant, or (d) selection of the appropriate washing parameters. Because detailed evaluation of these processing techniques was not practical during this program, only approaches involving washing techniques were investigated. These methods, once determined, could then be easily incorporated into the laboratory procedure.

TABLE 10

SULFATE RETENTION AS A FUNCTION OF WASH PROCEDURE AND REACTION CONDITIONS

Coal Mine	Seam	Run Number	Reaction Time (Hrs)	Mesh	Wash Procedure[a]	Sulfate Retention % w/w	Initial Sulfate % w/w
Edna	Wadge	Trial	12	100 x 0	Minimal	0.68	0.00
		1-3	23	100 x 0	Standard	0.49	
Navajo	Nos. 6, 7, 8	Trial	12	100 x 0	Minimal	0.54	0.03
		1-3	23	100 x 0	Standard	0.15	
Belle Ayr	Roland-Smith	Trial	21	100 x 0	Minimal	0.64	0.00
		1	6.5	100 x 0	Standard	0.14	
		2-3	10.5	100 x 0	Standard	0.14	
Colstrip	Rosebud	Trial	23	100 x 0	Minimal	0.23	0.00
		Trial	13	100 x 0	Minimal	0.06	
		1-3	12-13	100 x 0	Standard	0.06	
Weldon	Des Moines No. 1	Trial	14	100 x 0	Minimal	0.31	0.15
		1-3	23	100 x 0	Standard	0.18	
		4	13	200 x 0	Standard	0.12	
Eagle No. 2	Illinois No. 5	Trial	23	100 x 0	Minimal	0.85	0.04
		1-3	13-14	100 x 0	Standard	0.18	
		4	23	100 x 0	Standard	0.23	
Orient No. 6	Herrin No. 6	Trial	21	100 x 0	Minimal	0.45	0.01
		1-3	23	100 x 0	Minimal	0.62	
		4	23	200 x 0	Standard	0.35	
		5	13	200 x 0	Standard	0.17	
Camp Nos. 1 & 2	No. 9 (W. Ky.)	1-3	13	100 x 0	Minimal	0.42	0.06
		4	23	100 x 0	Standard	0.28	
		5	23	200 x 0	Standard	0.25	
		6	13	200 x 0	Standard	0.16	
Egypt Valley No. 21	Pittsburgh No. 8	Trial	13	100 x 0	Minimal	0.25	0.14
		1-3	13-22	100 x 0	Standard	0.11	
		4	13	200 x 0	Standard	0.13	
No. 1 (Dixie Fuel)	Mason	Trial	12	100 x 0	Minimal	0.26	0.08
		1-3	23	100 x 0	Standard	0.09	
Jane	Lower Freeport	Trial	13	100 x 0	Minimal	0.06	0.00
		1-3	12-23	100 x 0	Standard	0.06	
Fox	Lower Kittanning	Trial	13	100 x 0	Minimal	0.31	0.05
		1-3	23	100 x 0	Standard	0.09	
		4	13	200 x 0	Standard	0.09	
(Green Co.)	Lower Kittanning	1-3	13	100 x 0	Minimal	0.30	0.10
Warwick	Sewickley	Trial	13	100 x 0	Minimal	0.35	0.01
		1-3	23	100 x 0	Standard	0.14	
		4	13	100 x 0	Standard	0.07	
Humphrey No. 7	Pittsburgh	Trial	14	100 x 0	Minimal	0.10	0.01
		1-3	23	100 x 0	Standard	0.10	

[a] See text for explanation of procedures

Table 11 summarizes sulfate extraction experiments performed on the treated Camp Nos. 1 and 2 coal. Note that both methanol and aqueous methanol are much less effective than water in reducing the sulfate content of the coal, but that the addition of 1% v/v sulfuric acid to aqueous methanol reduced the sulfate to 0.24% w/w. Because methanol is detrimental to sulfate removal, the use of 1% aqueous sulfuric acid could be even more effective. In addition, basic solutions such as 5% w/v sodium carbonate and 10% v/v concentrated ammonium hydroxide in aqueous methanol and chelating agents such as 3% w/w ethylenediamine tetracetic acid and 10% w/w tetraethylene tetramine are apparently slightly more effective than water in reducing the sulfate level.

TABLE 11

SPECIAL SULFATE REMOVAL EXPERIMENTS

CAMP NOS. 1 AND 2 COAL[a,b]

Experiment	Reagent	Temp., °C	Final % SO_4, w/w
1	H_2O	Reflux	0.19
2	CH_3OH	Reflux	0.33
3	aq.CH_3OH[c]	Reflux	0.49
4	1% H_2SO_4 in aq. CH_3OH[c]	Reflux	0.24
5	5% Na_2CO_3 in aq.CH_3OH[c]	Reflux	0.13
6	10% NH_4OH in aq.CH_3OH[c]	Reflux	0.20
7	3% EDTA in aq. CH_3OH[c]	Reflux	0.13
8	10% Tetraethylene tetramine in aq. CH_3OH[c]	Reflux	0.11

[a] Initial sulfate retention 0.42% w/w, the ratio of coal to extraction solution was 1:60 w/v

[b] Extraction time of four hours followed by thorough water wash

[c] Methanol: water ratio of 7:3

Table 12 summarizes a second set of sulfate extraction experiments performed on treated Orient No. 6 coal. With this coal, an additional wash with either water, 0.1-3N sulfuric acid or 1N oxalic acid for one hour at elevated temperature was effective in reducing the sulfate level from 0.62 to 0.25% w/w or less.

TABLE 12

SPECIAL SULFATE REMOVAL EXPERIMENTS

ORIENT NO. 6 COAL[a,b]

Experiment	Reagent	Temp., °C	Final % SO_4, w/w
1	H_2O	$\sim$90	0.25
2	0.1N H_2SO_4	$\sim$80	0.21
3	0.5N H_2SO_4	$\sim$80	0.23
4	1.0N H_2SO_4	$\sim$80	0.19
5	3.0N H_2SO_4	$\sim$80	0.23
6	1.0N H_2SO_4	$\sim$30	0.36
7	1N Oxalic Acid	$\sim$60	0.16

[a] Initial sulfate retention 0.62% w/w, the ratio of coal to extraction solution was 1:20 w/v

[b] Extraction time of one hour followed by thorough hot water wash

Washing with 1N sulfuric acid at 30°C (Expt. 6) was not nearly as effective giving a final sulfate value of 0.36% w/w and indicating that elevated temperature is necessary for more effective sulfate removal. However, since these results are from single experiments and the grouping of these values with the exception of Experiment 6 is so close, the remaining six methods in Table 12 should be considered equally effective at this point.

Based on the above experimentation, water washing as well as washing with dilute sulfuric acid is capable of removing residual sulfate. Dilute sulfuric acid should be also an advantage in those cases where basic iron sulfates are present. Basic solutions or chelating agents, though effective, will introduce unnecessary process expense and should not be considered if the above are effective. Therefore, the following standard procedure was adopted for the survey studies in order to ensure, without optimization, a low level of sulfate in the treated coals.

> The extracted coal is slurried with 2 ℓ of 1N sulfuric acid at ~80°C for 2 hours, filtered and stirred with another 2 ℓ 1N sulfuric acid at ~80°C for an additional two hours. After filtration, this procedure is repeated with 2 ℓ water at ~80°C. If scheduling does not permit the coal to be extracted with toluene immediately, stirring is continued at ~50°C for an extended period until filtration and extraction can be performed.

The results listed in Table 10 show that the final sulfate can be reduced to 0.06-0.14% w/w for Appalachian Basin coals, 0.16-0.35% w/w for the Eastern Interior Basin coals, 0.12-0.18% w/w for the Western Interior Basin coal (Weldon),and 0.06-0.49% w/w for the Western coals using this method. Thus, while not necessarily the best procedure, this standard method achieved an acceptable final sulfate level.

In order to determine how additional washing would affect sulfate levels, samples of the Egypt Valley No. 21, Fox, Warwick, and Humphrey No. 7 coals that had already been washed and extracted with toluene to remove elemental sulfur were refluxed in 1:20 w/v ratio of coal to both 1N and 0.1N sulfuric acid for four hours. After filtration and rinsing, the samples were refluxed in 1:20 w/v ratio of coal to water to remove residual acid and sulfate. This resulted, in all cases, in a sulfate level of <0.01% w/w.

In regard to sulfate retention, the following observations should also be considered:

- After minimal washing the Appalachian coals have a much lower sulfate retention than the other survey coals
- The final sulfate after washing seems to increase with increasing ferric sulfate leaching time
- The mesh size does not seem to affect the final sulfate retention

Thus, while the problem of sulfate retention has been reduced in importance, the amount of sulfate retained appears to depend somewhat on the individual characteristics of the coal. Also, the washing procedure used here, while fitting into the general constraints of the Meyers Process, has not been optimized. In particular, the use of a continuous counter current wash or multiple washes may be as effective as the prolonged washes used above. In addition, a sulfuric acid wash may not be necessary. Thus, for a complete understanding of the problem, several coals should be investigated in detail in order to determine the minimum conditions necessary for sulfate removal.

4.3.5 Ash Changes

Table 13 summarizes ash changes that occurred upon extraction of the coal with ferric sulfate. The calculated change was obtained by multiplying the absolute percent pyritic sulfur removed by 1.25 for upon ashing pyrite, FeS_2, is converted to iron oxide, Fe_2O_3, as follows:

$$FeS_2 + 2.75\ O_2 \longrightarrow 0.5\ Fe_2O_3 + 2\ SO_2$$

In all cases, more ash was removed than can be accounted for by pyrite removal alone. In general, excess removal was greatest for the Western and the Eastern Interior Basin coals. The only Appalachian coal with a high excess removal is the Warwick coal, which probably is the result of its very high 40.47% initial ash.

Since the aqueous extraction solution is both acidic and oxidizing, inorganic materials in the ash could be brought into solution by either an acidic or oxidizing attack. However, the most likely mechanism of solution probably is dissolution of basic inorganic compounds by the sulfuric acid that is present in solution. Since acid soluble compounds of sodium, potassium, magnesium and iron, such as oxides and carbonates, can be major constituents of coal ash, they could easily account for the excess ash removal. However, since research has thus far not accurately defined this situation, additional experimentation should be performed in order to establish purification requirements for recycled ferric sulfate streams. Operation of a continuous large-scale (pilot) facility may be required to completely clarify potential problems in this area.

4.3.6 Organic Sulfur Changes

After several coals had been extracted, the results seemed to indicate that the treated coal apparently had a higher organic sulfur content than the starting coal. Although organic sulfur increases of 0.01-0.12% w/w were attributable to ash removal, these did not account for all of the apparent increases. In addition, the organic sulfur value is the least accurate of all sulfur analyses because it is not determined directly

TABLE 13.

SUMMARY OF ASH CHANGES
(% W/W)[a]

MINE	SEAM	INITIAL	EXTRACTED	CHANGE	CALCULATED CHANGES[b]	EXCESS
Edna	Wadge	9.13	6.77	-2.36	-0.10	-2.26
Navajo	Nos. 6, 7, 8	25.29	20.53	-4.76	-0.30	-4.46
Belle Ayr	Roland-Smith	7.55	3.37	-4.18	-0.24	-3.94
Colstrip	Rosebud	10.38	5.17	-5.21	-0.35	-4.86
Weldon	Des Moines No. 1	15.74	6.43	-9.31	-5.96	-3.35
Eagle No. 2	Illnois No. 5	26.53	19.80	-6.73	-2.96	-3.77
Orient No. 6	Herrin No. 6	22.51	18.85	-3.66	-1.23	-2.43
Camp Nos. 1 & 2	No. 9 (W. Ky.)	21.13	15.77	-5.36	-2.73	-2.63
Egypt Valley No. 21	Pittsburgh No. 8	25.29	18.86	-6.43	-5.56	-0.87
No. 1 (Dixie Fuel)	Mason	11.39	8.50	-2.89	-2.21	-0.68
Jane	Lower Freeport	21.75	17.99	-3.76	-1.63	-2.13
Fox	Lower Kittanning	13.55	9.72	-3.83	-3.40	-0.43
Warwick	Sewickley	40.47	35.32	-5.15	-1.25	-3.90
Humphrey No. 7	Pittsburgh	9.88	6.97	-2.91	-1.81	-1.10

a) All values in the table are in % W/W and are an average of two or more values based on runs 1, 2 and 3 in Appendix D.
b) Based on pyrite removed.
c) Runs using 200 mesh X 0 coal.

but by subtracting the amount of pyritic and sulfate sulfur from the total sulfur. For this reason the organic sulfur value contains resultant errors from all three analyses. Thus, according to ASTM Standards, duplicate organic sulfur values with spreads of up to 0.4-0.6% w/w can be considered acceptable for analyses done by different operators in different laboratories. The problem is made even more ambiguous due to the possibility that treating the coal with ferric sulfate solution can introduce a systematic error in the results. Therefore, a thorough statistical analysis was made in order to assess the validity of the indicated results.

The statistical analysis of the organic sulfur data is tabulated in Table 14. Note that the actual percent w/w differences were corrected for any expected increase due to actual ash removal (see Table 13). Single runs are included for informational purposes even though only limited statistical information can be obtained from them. In the fourteen cases where multiple runs were performed, six show an increase of more than +0.1%, and one shows a difference of -0.14%. Of the remaining seven cases, four show an increase of less than 0.1% and three a decrease of less than 0.1%.

All the data were then tested for significance by applying the *t* test in which the value of *t* was calculated according to the equation:

$$t = \frac{(\overline{B} - \overline{A})\sqrt{n}}{\sigma_d}$$

where $\overline{A}$ = average starting organic sulfur,
$\overline{B}$ = the average final organic sulfur,
n = the number of values in each set, and
σ_d = the standard deviation of the difference $\overline{B} - \overline{A}$

The value of *t* is then used to determine the level of significance by consulting a standard table of values used for the *t* distribution (2).

From an analytical point of view a systematic error of 0.1% is easily possible and from a practical perspective differences less than 0.1% are not important; therefore, the data were tested for statistical significance for a difference >0.1% w/w. Using this criterion, the Weldon, Egypt Valley No. 21, Fox, and Warwick coals had >0.1% w/w organic sulfur increase with a significance of 90 or more percent. The No. 1 (Dixie Fuel) and the Humphrey No. 7 mines were significant at the 80% and 70% levels, respec-

TABLE 14

SUMMARY OF ORGANIC SULFUR DATA

Mine	Seam	Run	Total Run Time	Mesh[c]	Organic Sulfur, % W/W					Significance Level for Increase[b]	
					Initial	Final	Difference	Calc. Incr.[a]	Corrected Difference	>0.1%	>0.2%
Edna	Wadge	1-3	23	100	0.61 ± .038	0.59 ± .043	-0.02 ± .057	.02	-0.04 ± .057	None	-
Navajo	Nos. 6, 7, 8	1-3	23	100	0.50 ± .044	0.57 ± .077	+0.07 ± .089	.03	+0.04 ± .089	None	-
Belle Ayr	Roland-Smith	1-3	6-10	100	0.54 ± .035	0.65 ± .030	+0.11 ± .046	.02	+0.09 ± .046	None	-
Colstrip	Rosebud	1-3	12-13	100	0.67 ± .019	0.57 ± .056	-0.10 ± .059	.04	-0.14 ± .059	None	-
Weldon	Des Moines No. 1	1-3	23	100	1.00 ± .069	1.69 ± .161	+0.69 ± .175	.10	+0.59 ± .175	95	90
		4	13	200		1.98	+0.98	.10	+0.88		
Eagle No. 2	Illinois No. 5	1-3	13-14	100	1.61 ± .156	1.68 ± .065	+0.07 ± .169	.12	-0.05 ± .169	None	-
		4	23	100		1.62	+0.01	.12	-0.11		
Orient No. 6	Herrin No. 6	1-3	23	100	0.36 ± .109	0.46 ± .095	+0.10 ± .145	.01	+0.09 ± .145	None	–
		4	23	200		0.69	+0.33	.01	+0.32		
		5	13	200		0.73	+0.37	.01	+0.36		
Camp Nos. 1 & 2	No. 9	1-3	13		1.65 ± .130	1.73 ± .066	+0.08 ± .146	.09	-0.01 ± .146	None	-
		4	23	100		1.89	+0.24	.09	+0.15		
		5	23	200		2.08	+0.43	.09	+0.34		
		6	13	200		1.72	+0.07	.09	-0.02		
Egypt Valley No. 21	Pittsburgh No. 8	1	13-22	100	1.34 ± .026	2.16 ± .182	+0.82 ± .184	.09	+0.73 ± .184	95	95
		4	13	200		2.20	+0.86	.09	+0.77		
No. 1(Dixie Fuel)	Mason	1-3	23	100	1.06 ± .126	1.32 ± .133	+0.26 ± .183	.03	+0.23 ± .183	80	None
Jane	Lower Freeport	1-2	12-23	100	0.41 ± .051	0.49 ± .035	+0.08 ± .062	.02	+0.06 ± .062	None	-
Fox	Lower Kittanning	1-3	23	100	0.69 ± .044	1.18 ± .206	+0.49 ± .211	.03	+0.46 ± .211	90	80
		4	13	200		0.99	+0.20	.03	+0.17		
Warwick	Sewickley	1-3	23	100	0.27 ± .088	0.59 ± .061	+0.32 ± .107	.01	+0.31 ± .107	90	70
		4	13	100	0.53	0.53	+0.26	.01	+0.25		
Humphrey No. 7	Pittsburgh	1-3	23	100	0.98 ± .120	1.25 ± .088	+0.27 ± .148	.03	+0.24 ± .148	70	70

[a] Increase due to ash removal, see Table 13

[b] No statistical calculations were made on single runs

[c] 100 mesh X 0 and 200 mesh X 0 is symbolized as 100 and 200, respectively

tively. When tests were made for significance for differences >0.4% w/w, the Weldon and Egypt Valley No. 21 coals still had 80% significance, while the Fox and Warwick coals began losing significance at the 0.2% difference level.

The data were further examined for geographic correlations. The Eastern Interior Basin coals showed no statistical differences between the starting and final coal analyses, while the coals from the Western U. S. showed no gain at the 0.1% level. The Western Interior Basin coal and six out of the seven Appalachian coals showed significant increases at the 0.1% level. The reader should note, however, from the single runs which are listed that individual final organic sulfur values can vary considerably. Also, the Orient No. 6, Camp Nos. 1 and 2, and Weldon samples ground to 200 mesh x 0 showed greater final organic sulfur content while the Fox sample shows less.

The selection of coals was not extensive enough to make comparison between seams. However, both the Egypt Valley No. 21 and Humphrey No. 7 coals were from the Pittsburgh seam, and while the former showed a substantial increase, the latter showed only a slight increase, indicating that perhaps local rather than general factors determine the amount of increase.

These organic sulfur increases could result from three possible sources: (a) actual organic sulfur increases caused by either sulfonation or sulfation reactions, or (b) apparent organic sulfur increases caused by formation of unextractable inorganic sulfur species during coal leaching, and (c) incomplete removal of elemental sulfur in the toluene extraction step. Partially oxidized coals, coals with many phenolic groups of other active sites, or highly porous coals with a large internal surface area should be prime candidates for sulfonation or sulfation. Coals of this type included in the survey are the Western and the Western and Eastern Interior Basin coals. In fact, these two groups of coals in general had a higher ferric ion consumption (see Table 9) than the Appalachian coals. Ferric ion oxidation of coal should typically produce phenols, alcohols and other reactive sites which could easily react with the sulfuric acid present in any extraction. Since both of these groups of coals did not show a significant organic sulfur increase, the possibility of sulfonation or sulfation reactions is presently considered unlikely.

Apparent organic sulfur increase could result from insoluble inorganic compounds such as $CaSO_4$ or $Fe(OH)SO_4$ precipitating in the pores of tightly structured coal such as is the case for most Appalachian coals. Coals with high pyritic sulfur contents such as Egypt Valley No. 21, Weldon, and Fox could produce significant amounts of sulfate internally which could precipitate as $CaSO_4$ in the coal pores by reactiong with CaO or $CaCO_3$ present in all coal ash or could form insoluble $Fe(OH)SO_4$ under appropriate conditions. Even though the analytical procedure for hydrochloric acid extraction of sulfate sulfur was designed specifically to remove sulfate formed by oxidation or weathering and thus could very well miss deeply imbedded inorganic material, it seems unlikely that more than 0.1% sulfate sulfur could be missed in the analysis even in the Appalachian coals.

The third possibility is the incomplete removal of the elemental sulfur in the toluene extraction step. This sulfur would raise the total sulfur value but not result in erroneously high pyritic or sulfate sulfur values. Because organic sulfur is calculated by difference, this additional sulfur would then result in a higher organic sulfur value. Since the extraction step has not been optimized and is presently performed only once, this source should be considered an excellent possibility. In addition, this residual elemental sulfur would be expected to be the greatest in the highly structured and small-pored Appalachian coals, and less in the more porous Internal Basin and Western coals. Because actual results follow these trends, it is felt that this is the probable source of the organic sulfur increase. Additional experimentation is required to confirm this possibility and to establish tentative solutions.

4.3.7 Miscellaneous Data

Table 15 contains miscellaneous data which was accumulated during this survey and which is treated briefly in the paragraphs below:

> The Free Swelling Index (FSI) is an indication of the caking qualities of a coal and thus has some importance in evaluation of a coal for coking and for use in certain types of steam boilers. The data shows that, with coals that have high excess reactivity with ferric ion (such as the Eastern Interior Basin coals), the FSI is reduced substantially. Coals that have little excess reactivity with ferric sulfate (such as the Appalachian Basin coals) had little or no change upon treatment. This is consistent with the generally accepted idea that slight oxidation of a coal reduces its FSI.

TABLE 15

MISCELLANEOUS DATA

COAL	SEAM	FREE SWELLING INDEX		RANK		NITROGEN, % W/W			
		INITIAL	EXTRACTED	INITIAL	EXTRACTED	INITIAL	TREATED	TREATED CORR.[a]	FILTRATION RATE[b]
Edna	Wadge	0.5	0	hvCb	hvCb	-	-	-	M
Navajo	Nos. 6, 7, 8	0	0	hvCb	subA	-	-	-	F
Belle Ayr	Roland-Smith	0	0	subA	subB	0.99	1.11	1.06	F
Colstrip	Rosebud	0	0	subB	subB	1.09	1.05	1.00	F
Weldon	Des Moines No. 1	1	0	hvCb	hvCb	-	-	-	M
Eagle No. 2	Illinois No. 5	6	2 1/2	hvAb	hvAb	1.31	1.40	1.34	S
Orient No. 6	Herrin No. 6	4 1/2	0	hvAb	hvBb	1.56	1.50	1.44	M
Camp Nos. 1 & 2	No. 9 (W. Ky.)	5	0	**hvBb**	**hvBb**	1.32	1.38	1.31	S
Egypt Valley No. 21	Pittsburgh No. 8	4	4	hvAb	hvAb	1.12	1.25	1.17	M
No. 1[c]	Mason	-	-	hvAb	hvAb	-	-	-	M
Jane	**Lower Freeport**	6 1/2	5	hvAb	hvAb	1.24	1.33	1.28	F
Fox	Lower Kittanning	6	7	hvAb	hvAb	1.39	1.59	1.53	F
Greene County[d]	Lower Kittanning	5 1/2	6	mvb	mvb	-	-	-	M
Warwick	Swickley	4 1/2	-	hvAb	hvAb	1.10	1.22	1.16	M
Humphrey No. 7	Pittsburgh	8	8 1/2	hvAb	hvAb	1.60	1.55	1.50	M

a) Corrected to reflect the smaller amount of ash present in the treated sample. It was assumed no nitrogen was present in the ash.

b) Filtration of leach solution slurry containing 100 mesh x 0 coal; 200 mesh x 0 slurrys filtered slower; see text for details

c) Dixie Fuel Co.

d) Lower Kittanning coal from previous bench-scale program(1).

Nitrogen Content - The nitrogen content of the treated and untreated coals was monitored on the same 10 group samples that were analyzed for trace element changes. Since it can be safely assumed that the nitrogen is primarily organic in nature, the nitrogen values of the treated coals were corrected for ash loss upon extraction. When these values are compared to the original values, there are no significant differences,indicating that the nitrogen content of the coals is not affected by the leaching process.

The Filtration Rates of the various coals are qualitatively shown in the last column of Table 15. These observations are based on the amount of time required to obtain a dewatered filter cake from 100 g of 100 mesh x 0 coal in 2.5 ℓ of leach solution. A label of fast(F) indicates no problem in filtration with the rate proceeding near the maximum rate of the funnel; medium (M) indicates a slower, but still acceptable rate; and slow (S) indicates that unacceptably long times were required for filtration. Coals ground to 200 mesh x 0 always filtered slower.

Rank - The rank of the treated and untreated coals is the same in all instances except for the Orient No. 6, Belle Ayr and Navajo coals. Because rank is determined only heat content for hvAb and lower ranked coals, only minor differences in rank should be expected because rank is quite insensitive to small btu changes.

4.4 FLOAT-SINK TESTING

Float-sink testing (washability studies) were run on eleven of the fifteen coals by Commercial Testing and Engineering Company in order to determine how conventional float-sink procedures compare to the Meyers Process in efficiency of pyrite removal, heat content change, and ash loss. In addition, information was obtained that can be used to evaluate a combined two-step process involving coal washing followed by the Meyers Process that would produce coal containing minimum amounts of pyrite and ash and a maximum of heating value.

4.4.1 Procedures

The mine samples, representing fifteen mines and coal seams, were selected, sampled and prepared according to the procedures described in Section 4.2 of this report. No tests were run on the four samples from the Edna, Navajo, Belle Ayr and Colstrip mines since they contained less than 0.3% w/w pyritic sulfur and 1.0% total sulfur and were judged economically unfeasible for washing in order to remove pyritic sulfur.

Five hundred pounds each of the 1-1/2" x 100 mesh, 3/8" x 100 mesh and 14 mesh x 0 portions obtained from the initial sampling of the coals were fractionated according to standard float-sink procedures using organic liquids of 1.30, 1.40, 1.60 and 1.90 specific gravities. Head samples for each size (or grind), each gravity portion and the two 100 mesh x 0 samples were analyzed on a dry basis for % w/w ash, total sulfur and pyritic sulfur.

The raw data were then used to calculate washability data showing cumulative recovery and cumulative reject at the various specific gravities for each of the size portions. A complete set of tables showing all the data is included in Appendix E.

4.4.2 Results and Discussions

Table 16 shows the summary of the results for the 14 mesh x 0 portions at 1.90 and 1.60 specific gravities and how they compare to the Meyers Process for total sulfur and pyritic sulfur reductions and ash removal. The 14 mesh x 0 portions, even though it may be too fine a grind to be used in a commercial installation, was chosen because in most instances this size generates the best results that can be obtained by float-sink procedures.

TABLE 16
SUMMARY OF FLOAT-SINK TESTS
14 MESH X 0 COAL
COMPARISON TO MEYERS PROCESS

Mine	Seam	Initial Analysis, % w/w			Washed Coal Analysis, % w/w 1.90 Float Material				Washed Coal Analysis, % w/w 1.60 Float Material				Meyers Process Final Analysis, % w/w				
		% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Rec'vy[c]	% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Rec'vy[c]	% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Rec'vy[c]	% Total Sulfur	% Pyritic Sulfur	% Ash	Source Run No
Weldon	Des Moines No.1	6.39	5.24	15.74	97	3.91	2.72	8.81	95	3.81	2.60	8.20	98	2.25	0.15	5.94	4
Eagle No. 2	Illinois No.5	4.29	2.64	26.53	97	2.92	1.53	12.52	94	2.77	1.35	10.44	100	1.97	0.11	19.49	2
Orient No.6	Herrin No. 6	1.66	1.30	22.51	98	1.38	0.80	10.35	96	1.34	0.75	8.96	95	0.93	0.06	18.85	5[a]
Camp Nos.1&2	No. 9 (W.Ky)	4.51	2.80	21.13	96	2.90	1.22	10.21	91	2.75	1.01	8.49	100	2.02	0.14	15.77	6[a]
Egypt Valley No.21	Pitts. No.8	6.55	5.07	25.29	96	4.63	3.42	11.86	92	4.27	3.03	10.25	100	2.71	0.38	18.69	4
No.1(Dixie Fuel)	Mason	3.12	1.98	11.39	97	2.29	1.03	6.77	96	2.15	0.88	6.31	95	1.62	0.21	8.50	1-3
Jane	Lower Freeport	1.85	1.44	21.75	97	0.78	0.40	11.15	95	0.70	0.31	9.40	100	0.69	0.14	17.99	1-2
Fox	Lower Kittanning	3.83	3.09	13.55	98	2.00	1.32	8.78	95	1.90	1.21	7.44	99	1.64	0.37	9.72	1-3
Warwick	Sewickley	1.37	1.09	40.47	93	1.02	0.54	17.02	89	0.92	0.41	12.96	100	0.66	0.06	35.32	4[a]
Humphrey No.7	Pittsburgh	2.58	1.59	9.88	99	1.90	0.90	6.97	97	1.82	0.81	6.45	100	1.49	0.14	6.97	1-3
Walker	Upper Kittanning	0.71	0.07	16.67	98	0.66	0.07	12.17	93	0.66	0.07	9.59	-	-	-	-	-[b]

[a] No ash values available - a typical value from runs 1-3 was selected

[b] Not run due to low pyritic sulfur.

[c] See text for method of calculation.

The 1½" x 100 mesh portions from the Eagle No.2 and Humphrey No.7 mines gave results similar to that of the 14 mesh x 0 portions and in the case of the Weldon coal, better results were observed. With all other coals, coal cleaning potential decreased when washing coarser material.

In Table 16 the % float-sink btu/lb loss was calculated from the % w/w and ash content of the cumulative material rejected at the specific gravity of interest. This value was assumed to represent the total heat content loss and was subtracted from 100% to give the btu recovery. For the Meyers Process complete organic material recovery was assumed because no evidence has been found to date that indicates material other than ash is dissolved in the leaching process. The percent heat content recovery was then calculated using the before and after dry, mineral matter free, pyrite btu free, heat content of the coal.

The analysis of the 1.90 float material shows that 0.1-1.9% w/w more total sulfur is removed from the coal by the Meyers Process when compared to the float-sink method. For the 1.60 float material the corresponding figure is 0.0-1.5% w/w with the majority of the values for both specific gravities being between 0.4 and 1.0%. It should be noted that commercial methods using 3/8" x 100 mesh or 1-1/2" x 100 mesh coal are not as efficient as the laboratory procedure using 14 mesh x 0 coal. On the other hand, larger chemical processes are often more efficient than laboratory scale, thus the Meyers Process may be more advantageous than is apparent from the present data.

The advantages of the chemical leaching is even more apparent from the final pyrite values. For all but three coals, the final pyrite values are between 0.06 and 0.15% w/w when the coals were treated by the Meyers Process; however, even when using the 1.60 float material, physical washing only gave final pyritic sulfur values between 0.8 and 3.0% w/w. The 1.60 float material of the washed Jane and Warwick coals had final pyritic sulfur of 0.3 and 0.4% w/w, respectively, making them possibly competitive with the Meyers Process. The two high values for chemical leaching of 0.4% for the Egypt Valley and Fox coals are still much better than 1.60 float material values of 3.0 and 1.2% for the washed coals. Note, however, that 90% pyrite removal is not always reflected in the total sulfur values due to slight increases in other sulfur forms. Although for approximately one-half of the coals the results are already near optimum (see Table 1), additional processing improvements will be necessary to reach near optimum values for the others. However, in each case the Meyers Process reduced the total sulfur content of the coals lower than that obtainable by conventional coal cleaning. In most cases, substantital differences were found.

The btu or heat content recovery for the 1.90 float material is 93-99% and for the 1.60 float material, it varies from 89-97% with a median value of 95%. In contrast, chemical leaching results in 98-100% btu recovery. Only the No.1 (Dixie Fuel)and the Orient No.6 coals reacted with the ferric sulfate leach solution sufficiently to cause heat content reductions as high as 5%. Thus, for almost every coal the Meyers Process is more efficient than physical separations with respect to btu recovery.

Table 16 also summarizes ash changes as the result of both processes. Note that in most cases, especially the Warwick, Jane, Egypt Valley No.21, Eagle No.2, Camp Nos.1&2 and Orient No.6 coals, substantially more ash is removed by physical cleaning compared to the Meyers Process (in which only ash corresponding to pyrite is removed). Only in low ash cases such as the Fox and Humphrey No.7 coals are both processes comparable. With the Walker coal which had essentially zero pyritic sulfur, only ash reduction was achieved. However, ash reduction in itself is valuable in that reduced shipping costs, reduced load on electrostatic precipitators and enhanced heating values are realized. In addition, a certain part of the ash is soluble in the leach solution of the Meyers Process and any initial ash reduction should reduce purification requirements on this solution, and depending upon pyrite reduction, operating costs of the Meyers Process. Thus, depending on the situation, a simple washing procedure on coals containing >20% w/w ash may be advantageous prior to treatment with the Meyers Process.

4.5 ORGANIC SULFUR EXTRACTION EXPERIMENTATION

From the previous bench-scale program (Ref.1) studies for the removal of organic sulfur from coal p-cresol appeared to offer promise for partitioning coal into organic sulfur rich and organic sulfur lean fractions according to data obtained by analysis of the extracted and unextracted coal. However, analysis of the extracted portion did not confirm these results. It was the objective of this survey program to assess the effect of p-cresol on various types of coals in order to obtain additional information regarding the possibility of organic sulfur partition. The results are presented below.

4.5.1 Baseline Conditions

The baseline conditions for organic sulfur removal were determined from the work performed under Contract EHSD 71-7 (Ref.1). A discussion of the various test parameters is presented below:

- Mesh Size - coal that has been ground to 100 mesh x 0 gives the highest apparent organic sulfur removal and is easily handled in the laboratory.
- Reaction Time - extraction for 1.25 hours was used since this allows adequate time for extraction without excessive dissolution or degradation of the coal.
- Solvent Ratio - p-cresol was identified as the most effective solvent for experimentation on removal of organic sulfur from coal. A ratio of 1:4 w/v was effective and desirable from a laboratory standpoint.
- Reaction Temperature - a reaction temperature of 180-200°C was used for sulfur removal. Since water in the coal can drastically lower the reflux temperature of p-cresol, the coal was dried under vacuum at 120°C before use.
- Post Sample Treatment - after extraction, the samples were filtered, washed with fresh p-cresol, and then dried. All calculations were performed on a dry basis in order to eliminate variables from wetness of coal. Sulfur forms and proximate analyses were obtained on each treated coal sample.
- Material Balance - a coal and sulfur material balance was obtained by weighing the coal before and after treatment and recovering the dissolved solids from solution by distilling the cresol. The residue was analyzed to complete the sulfur balance.

4.5.2 Experimental Procedure

Seven survey program coals have been extracted in triplicate according to the following procedure:

> One hundred grams of coal were dried in a vacuum oven for 8 hours at 120°C. The dried coal was then added to 400 ml p-cresol at 195°C. The mixture was refluxed for 1.25 hours. The reflux temperature was 185-202°C depending on the relative dryness of the coal, with most of the runs being performed at >195°C. The mixture was filtered, washed with 200 ml cold p-cresol and dried in a vacuum oven at ∿160°C for at least 36 hours. The extracts and all trap materials were then combined for each set of triplicate runs. This solution, containing dissolved coal and sulfur compounds, was then reduced to dryness by vacuum distillation at 120°C. The extracts were then further dried at ∿160°C for at least 36 hours in a vacuum oven.

In order to insure that no sulfur compounds escape into the atmosphere, the exit gases from the reaction, vacuum distillation and filtration flasks as well as the oven were passed through a dry ice-acetone (78°C) trap. These traps were all checked for weight loss and evolution of volatile sulfur compounds. The results were negative in all cases. The material from the traps used for the vacuum distillation and final oven drying of the extracts is being saved for further analysis if warranted.

4.5.3 Organic Sulfur Extraction Results

The average starting and final sulfur forms and proximate analyses are given in Tables 17 and 18. Because dissolving the organic matrix of the coal has the effect of raising the ash content of the undissolved coal (as well as pyritic sulfur content) with the resulting dilution of the remaining organic sulfur, the organic sulfur values of the initial, final and extracted coal were converted to dry mineral matter free values using the Parr Formulae (ASTM Standard D388) and are listed in Table 19. These data show the problems attendant with obtaining the organic sulfur content by the difference between the total sulfur content and the sum of pyrite and sulfate contents. The inherent errors of the individual determinations and errors introduced during handling operations, together with those arising from calculations involving differences, tend to obscure the validity of the data. For these reasons, more meaningful data would be obtained if a direct organic sulfur content analysis method were available.

TABLE 17
EXTRACTION OF ORGANIC SULFUR - DRY BASIS SULFUR FORMS ANALYSIS

Coal	Total Sulfur, % w/w		Pyritic Sulfur, % w/w		Sulfate Sulfur, % w/w		Organic Sulfur, % w/w	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Eagle No. 2	4.29±.02	4.16±.14	2.64±.15	3.07±.21	0.04±.02	0.06±.01	1.61±.16	1.18±.25
Camp Nos.1&2	4.51±.05	5.18±.11	2.80±.12	3.84±.25	0.06±.00	0.06±.02	1.65±.13	1.28±.27
Orient No. 6	1.66±.07	1.83±.04	1.30±.08	1.36±.06	0.00±.01	0.00±.01	0.36±.11	0.47±.07
Belle Ayr	0.76±.03	0.79±.08	0.22±.02	0.31±.07	0.00±.00	0.00±.01	0.54±.04	0.48±.10
Fox	3.83±.04	4.13±.06	3.09±.02	3.79±.06	0.05±.02	0.01±.02	0.69±.04	0.33±.09
Jane	1.85±.02	2.08±.09	1.44_.05	1.72±.03	0.00±.01	0.00±.01	0.41±.05	0.36±.09
Colstrip	1.01±.01	0.90±.06	0.34±.02	0.33±.03	0.00±.00	0.01±.01	0.67±.02	0.56±.07

TABLE 18

EXTRACTION OF ORGANIC SULFUR-DRY BASIS PROXIMATE ANALYSIS

	Ash, % w/w		Volatile Matter, % w/w		Fixed Carbon, % w/w		Heat Content, btu/lb		Rank	
Coal	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Eagle No. 2	26.53±.20	30.58±.36	34.30±.61	29.80±.25	39.17±.41	39.61±.40	10566±186	9788±74	hvAb	hvAb
Camp Nos.1&2	21.13±.39	25.66±.55	35.86±.67	33.23±.51	43.01±.68	41.11±.36	11105±101	10497±120	hvBb	hvAb
Orient No. 6	22.51±.10	24.55±.44	31.67±.31	30.20±.71	45.82±.34	45.25±.61	11163±03	10661±139	hvAb	hvAb
Belle Ayr	7.55±.06	7.78±.03	47.11±1.55	46.74±1.17	45.34±1.50	45.47±1.20	12034±75	11955±142	subA	subA
Fox	13.55±.03	16.49±.21	38.33±.58	34.89±.81	48.12±.56	48.62±.78	12973±18	12249±55	hvAb	hvAb
Jane	21.75±.08	25.48±.20	30.07±.29	27.71±.80	48.18±.25	46.81±1.00	11932±38	11110±87	hvAb	hvAb
Colstrip	10.38±.08	10.28±.63	43.09±.73	40.63±1.67	46.53±.80	49.09±1.06	11591±67	11374±463	subB	subB

The results presented in Table 19 show that there is little or no statistically significant organic sulfur removal, and in one case (Orient No.6 coal) there is an organic sulfur gain. The conclusion that little organic sulfur is extracted is substantiated from the measurement of the sulfur content of the p-cresol extract and its relationship to the weight of coal in the extract. As shown in Table 19 the sulfur content of the extract is nearly identical to the initial coal sulfur content, which indicates that no selective extraction of sulfur was obtained. As a consequence of this finding, further studies of selective organic sulfur removal with p-cresol should be discontinued.

TABLE 19
ORGANIC SULFUR REMOVAL CALCULATIONS

Coal	Dry Mineral Matter Free Organic Sulfur, % w/w					Organic Sulfur Removal[a] % w/w
	Coal			Extract Composition		
	Initial	Final	Δ Sulfur	Ash, % w/w	Sulfur, % w/w	
Eagle No. 2	2.33±.16	1.70±.25	-0.63±.30	0.18	1.86±.04	27±12
Camp Nos. 1&2	2.22±.13	1.70±.27	-0.52±.30	0.20	1.92±.09	23±13
Orient No. 6	0.48±.11	0.63±.07	+0.15±.13	0.21	0.60±.05	-31±33
Belle Ayr	0.59±.04	0.52±.10	-0.07±.11	0.26	0.41±.01	12±18
Fox	0.83±.10	0.39±.09	-0.44±.14	0.15	0.89±.01	53±12
Jane	0.54±.05	0.43±.09	-0.11±.10	0.13	0.52±.04	20±18
Colstrip	0.76±.02	0.63±.07	-0.13±.07	0.05	0.52±.10	17± 9
						17±18

[a] The calculated standard deviation contains uncertainties in the sulfur determination. Uncertainties in the more precise ash determination are ignored.

4.6 TRACE ELEMENTS IN COAL

The primary objective of the trace element analysis portion of this program was to assess the effects that the Meyers Process for chemical desulfurization of coal would have on the levels of trace elements in various U.S. coals. The process for removing pyritic sulfur may well remove some of the trace elements which are present in many coals and which may be emitted as air pollutants upon combustion.

Trace element distributions have only recently been determined for a few coals. Table 20 shows trace element distributions on two coals analyzed by the Illinois Geological Survey and indicates the approximate levels and ranges of elements to be expected in coals. Since little work had been reported on trace element analysis in coal, no well established analytical methods were available at the start of this program, and, consequently, new procedures had to be developed to meet the objectives of this program.

4.6.1 Coal Composition

The following sections describe coal composition analysis methods and procedure assessments.

The broadest classifications which can be applied to the overall coal composition are mineral matter, organic matter, and moisture. The mineral matter normally comprises 5-40% of the coal composition. By far the majority of the mineral matter in coal belongs to shale, kaolin, and and sulfide groups which, when ashed, produce metal oxides of Si, Al, Fe, and Ti, as well as oxides of the alkali and alkaline earth metals. These major species, as well as P_2O_5, are economically determined for coal and coke ash using ASTM 2795 procedures. Trace elements that were of interest in this removal study included Ag, As, B, Be, Cd, Cr, Cu, F, Li, Hg, Pb, Mn, Ni, Sb, Se, Sn, V, and Zn.

TABLE 20

REPORTED TRACE ELEMENTS DISTRIBUTION IN TWO COALS

Element	(Parts Per Million - PPM) IGS C-15566[a]	NBS Coal[b]
Hg	0.49	0.17
Sb	8.9	
Mn	90	38
Ga	7.5	
Se	1.2	2.8
As	93	5.7
Br	10	
P	29	
V	15	54
Be	2.9	1.8
Cu	25	28
Ni	60	26
Zn	213	
Pb	183	24
Ge	35	1.9
Cr	4	22
Co	23	8.6
Cd	0.9	<0.4
B	115	43
F	(93) 46	80
Sn	<1.8	9.6
Mo	6.2	
Ag		<4

[a] Illinois Geological Survey reference coal number C-15566.

[b] National Bureau of Standards "standard" coal (see Appendix H).

4.6.2 Methods for Trace Element Analysis

Several criteria are involved in the selection of appropriate trace element analytical procedures. Of these, sensitivity, accuracy, precision and selectivity are of primary importance. Scope, sampling and standards requirements, cost of equipment and time for analysis are considerations of great practical significance.

Sensitivity in analytical chemistry reflects the ability to discern the difference between very small amounts of a substance. Detectability refers to the smallest quantity of a substance which can be determined with a specified degree of confidence. For the purposes of this program, the required sensitivity of a trace determination is recommended to be around a few ppm. In practical terms, this would represent an emission from a 100 ton/hr power plant of <0.5 lb/hr.

In describing the analysis result, accuracy and precision are frequently used rather loosely. Accuracy as normally refers to deviation of the determined value from the true value. Precision refers to deviation among determined values regardless of accuracy. Since the purpose of this program was primarily to determine the effectiveness of the extraction processes, an analytical precision of ±10% relative (σ) was recommended for the trace element determination. Since no standard methods were available for analyzing coal samples for trace elements, no level of accuracy could be set. If there were a problem with the accuracy of the analytical method used, the trouble or error would, hopefully, be systematic and have no effect on the conclusions reached about the removal of the trace elements from coal.

Of the several methods generally used for trace element analyses, three fit the overall requirements of the proposed study. These were spectrophotometry and fluorometry, atomic emission and absorption spectroscopy and instrumental neutron activation analysis. A comparison of these methods is presented in Table 21, based upon the criteria established above. In this table, a method was judged not applicable if it could not achieve the stated precision, sensitivity and assumptions about accuracy or if the analysis represented too high a cost. The information in Table 21 shows that instrumental neutron activation analysis was applicable only to two

TABLE 21
Trace Analysis Sensitivities
(ppm in moisture free whole coals)

Element	Instrumental Neutron Activation Analysis* (INAA)	Flame Absorption and Emission Spectroscopy**	Spectrophotometry and Fluorometry***
Hg	3	2	--
Be	NA	<1	--
Pb	NA	<1	1
F	NA	NA	1
Cd	5	<1	NA
As	1	10	1
Ni	NA	<1	NA
V	<1	10	--
Mn	<1	<1	NA
Cr	1	<1	1
Se	1	1	1
Cu	1	<1	1
Zn	1	<1	NA
B	NA	20	1
Sb	1	1	--
Ag	1	<1	1
Li	NA	<1	NA
Sn	3	5	--

*Data from Gulf General Atomic
**Data from Fisher Scientific
***Unpublished TRW results

thirds of the elements of interest. In addition, the cost of this method was judged higher than the other two methods. For these reasons, INAA was not used.

In considering atomic emission or absorption spectroscopy and spectrophotometric and fluorometric techniques, a careful approach to sample preparation must be established. In both of these cases, the element is actually determined in an aqueous solution. This necessitates ashing or digesting the coal prior to analysis. The data presented in Table 22 clearly show the undesirability of high temperature ashing procedures for sample preparation. The low temperature plasma ashing technique was preferred by TRW for trace element analyses over chemical digestion; however, both were studied in this program. In addition to the ashing requirement, spectrophotometric and fluorometric techniques frequently require liquid-liquid extractions of metal complexes to isolate the species in question or to remove interferences. Since atomic absorption and emission spectroscopy do not require such extractions, they were greatly preferred for the analyses of aqueous solutions. Only for the analyses of F, As, and B were the spectrophotometric and fluorometric techniques considered competitive or technically required.

In the course of this program, ten group samples (including raw coal, and the pyrite extraction product) were analyzed for the following trace elements: Ag, As, B, Be, Cd, Cr, Cu, F, Hg, Li, Mn, Ni, Pb, Sb, Se, Sn, V and Zn. The specific group samples analyzed were selected by the EPA Project Officer. The criteria for selection of the analysis procedures were:

1. a sensitivity of 1 ppm on a whole coal, dry weight basis
2. precision of ±10% relative (σ)
3. lowest cost among equivalent methods

Based upon these criteria, all the trace analyses except these for As, B and F were performed using atomic absorption spectroscopy. The elements As, B and F were determined spectrophotometrically. Details of the procedures development and the methods finally adapted are presented in Appendix H.

TABLE 22

Trace Element Retention*

Element	Low Temperature Ashing (100-120°C)	Muffle Furnace Ashing (550°C)	Wet Ashing
Pb	101%	46%	97%
Sn	95	87	112
Cu	98	92	96
Cd	92	53	100
Sb	99	46	97
Ba	97	99	96
Mn	99	107	103
Ni	97	99	99
Mo	98	116	100
Zn	96	39	99
Ti	95	92	93
Co	96	97	98
Cr	112	100	101

*Data from International Plasma Corporation.

4.6.3 Discussion of Trace Element Analysis Results

The results of trace element analyses for 18 elements in ten coals before and after treatment by the Meyers Process are presented in Appendix H, Tables H-4 through H-13. A summary of the trace element levels in the untreated coals appears in Table 23. All analyses were run in triplicate on both untreated and treated coals in order to get a good estimate of precision of the results and a reliable estimate of the trace element removal. These analyses were run on three separate samples of untreated coal in order that all sources of error such as sampling, ashing, dissolution, handling and final analysis would be included in the final precision estimate. In a similar manner, three separately extracted coal samples were each analyzed once for the composition of the treated coal.

Up to eleven sets of calculated standard deviations (σ) for each element in the untreated coal (a total of 18 groups) were used to calculate a pooled standard deviation (s) for each element. The same was done for the treated coal. The pooled standard deviation is calculated as follows:

$$S = \sqrt{\frac{\phi_1\sigma_1^2 + \phi_2\sigma_2^2 + \ldots\ldots \phi n\sigma n^2}{\phi_1 + \phi_2 + \ldots\ldots\ldots\ldots \phi n}}$$

σ = standard deviation for a given set of analyses
ϕ = number of analyses in a given set

The results of these calculations are given in Table 24 and show that on both an individual and an average basis, the results for the treated coal are only slightly less precise and in some cases much more precise than those on the untreated coal. Thus, the manipulation required in coal leaching apparently either did not introduce significant contamination or was introducing contamination in a fairly uniform way. Since both sets of data were similar, they were used to calculate a pooled standard deviation for the analysis of each element. These values are probably a more reliable estimate of the error associated with each analysis.

The final column in Table 24 lists the average of all values used in the error analysis. Because these values are a combination of results of extracted and unextracted coals and because values below the detection limits were not used, these numbers do not represent average levels of trace element in the coals studied.

Examination of the data in Table 23 shows that 7 of the 18 elements in this study occurred in the coals at levels which may be of minimal environmental significance from coal combustion facilities. The elements which occurred at levels less than 3 ppm are: Ag, Be, Cd, Hg, Sb, Se and Sn. In keeping with the low levels at which these elements were present, the % relative deviations of these analyses were generally high: Ag ±68%, Be ±27%, Cd ±44%, Hg ±27%, Sb ±91%, Se ±67%. For Sn no coal showed any value above the 2.5 ppm detection limit. Although no general conclusion can be made as to the removal of these elements by the Meyers Process, several showed some promise in cases where they were present in significant amounts. Particularly noteworthy is Se which was found in four coals at levels of 17, 5, 5 and 4 ppm and in each case was removed to less than the analysis limit of 2.5 ppm. Evidence also shows that when Be is present at levels greater than 1 ppm significant reductions could be obtained through application of the Meyers Process.

Five of the remaining elements - As, B, Cu, Li and Pb - were generally present in the range of 3-30 ppm while the remaining six - Cr, F, Mn, Ni, V and Zn - were generally above 30 ppm. The analytical precision of these eleven elements, while not as good as had been hoped, was generally acceptable: As ±15%, B ±12%, Cr ±5%, Cu ±11%, F ±14%, Li ± 10%, Mn ±9%, Ni ±13%, Pb ±44%, V ±25%, Zn ±8%. Notable exception are V and Pb for which unaccebtably high scatter was obtained. For these two elements several coals (5 for V and 4 for Pb) showed apparent increases after extraction, further indicating unidentified difficulties in the analyses. The problem with V is believed to be interelement interferences. The problem with Pb analysis is not now known.

A summary of trace element removals is presented in Table 25. Examination of the removal efficiency data indicates that As, Mn and Zn are effectively removed in all or nearly all of the coals studied. On the other hand, B, Cu and F showed insignificant levels of removal except for specific coals. The maximum removals for these three elements are: F-44%, B-87% and Cu-100%. Whether the occasional high values for B and Cu represent real differences in the mineral form present or simply anomalous data cannot be determined from the present study. The elements Cr and Ni generally showed good removal efficiencies with some unaccountable data. The data for Li showed

TABLE 23

TRACE ELEMENT COMPOSITION OF UNTREATED COALS
(PARTS PER MILLION, PPM)

Element	WESTERN COALS		EASTERN INTERIOR COAL BASIN			APPALACHIAN COAL BASIN				
	Belle Ayr	Colstrip	Eagle No.2	Orient No.6	Camp Nos.1&2	Egypt Valley No.21	Jane	Fox	Warwick	Humphrey No.7
Ag	<0.1	<0.1	<0.1	<0.1	8.	4.	2.	<0.1	4.	0.5
As	0.4	<0.01	6.6	15.2	5.7	22.2	28.9	23.5	12.9	9.1
B	11	35	30	43	272	34	27	16	20	26
Be	<0.5	0.5	0.5	6	1.5	0.7	0.8	2.0	1	0.4
Cd	0.6	<0.5	0.5	0.7	0.8	<0.5	<0.5	<0.5	<0.5	<0.5
Cr	<0.5	<0.5	126	74	122	55	55	94	81	26
Cu	27.3	8	18	36	17	26	35	25	24	16
F	47.9	29	151	105	215	168	122	93.5	251	78.5
Hg	0.22	0.20	0.16	0.12	0.16	0.31	0.11	0.07	0.14	0.06
Li	<0.3	4	4	23	10.5	26	38	4	76	13
Mn	48	87	86	57	98	41	46	24	31	31
Ni	61	31	136	53	27	41	33	147	44	17
Pb	3	3	29	0.5	25	15	25	5	16	7
Sb	2	1	1	<1	<1	<1	<1	<1	<1	<1
Se	5	<2.5	4	5	<2.5	<2.5	<2.5	17	<2.5	<2.5
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
V	1	103	64	69	105	102	147	94	78	77
Zn	49	9	215	25	97	31	34	105	55	18

TABLE 24

POOLED STANDARD DEVIATIONS
(PARTS PER MILLIOM, PPM)

Element	s Untreated[a](n)[b]	s Treated[a] (n)	s Total[a]	Average[c]
Ag	2.01 (5)	2.50 (6)	2.30	3.4
As	2.29 (11)	1.01 (8)	1.88	12.8
B	7.65 (12)	1.69 (9)	5.89	48.7
Be	0.49 (9)	0.19 (6)	0.40	1.5
Cd	0.36 (11)	0.30 (2)	0.35	0.8
Cr	3.03 (10)	4.10 (9)	3.58	74.2
Cu	2.52 (12)	2.76 (9)	2.62	23.1
F	12.15 (11)	23.94 (9)	18.41	128.1
Hg	0.036 (12)	0.054 (9)	0.045	0.17
Li	2.73 (11)	1.37 (10)	2.19	22.7
Mn	5.56 (12)	3.04 (10)	4.58	53.4
Ni	7.96 (12)	5.48 (9)	7.01	55.9
Pb	4.05 (11)	6.53 (9)	5.31	12.1
Sb	1.18 (3)	- -	1.18	1.3
Se	5.91 (5)	1.15 (2)	5.03	7.5
Sn	-	-	-	-
V	19.80 (12)	20.47 (9)	20.10	79.4
Zn	5.26 (12)	6.06 (10)	5.64	72.7

[a] Untreated = raw coal; treated = extracted coal; total = all sets of data from treated and untreated coal.

[b] Number of sets of data included, includes data from NBS coal analysis.

[c] Average of all numbers used for calculation; "less than" values were not used.

TABLE 25
TRACE ELEMENT REMOVAL
(% W/W)

	WESTERN COALS		EASTERN INTERIOR COAL BASIN			APPALACHIAN COAL BASIN				
Element	Belle Ayr	Colstrip	Eagle No. 2	Orient No. 6	Camp Nos. 1 and 2	Egypt Valley No. 21	Jane	Fox	Warwick	Humphrey No. 7
Ag	Ind[a]	Ind	Gain	Ind	50±33	50±15	N.D.	N.D.	N.D.	N.D.
As	N.D.[b]	Ind	90±17	88±3	82±9	85±6	81±7	94±5	∿100	91±1
B	N.D.	86±2	N.D.	30±8	87±1	N.D.	70±2	19±9	18±25	38±9
Be	Ind	Ind	Ind	92±48	67±27	43±16	<38	70±14	N.D.	N.D.
Cd	Ind	Ind	Ind	71±45	N.D.	Ind	Ind	Ind	Ind	Ind
Cr	Gain	Gain	71±5	23±6	45±30	N.D.	60±14	58±5	41±4	N.D.
Cu	19±7	Gain	Gain	100±11	N.D.	35±9	11±4	44±6	N.D.	N.D.
F	44±9	N.D.	N.D.	14±2	N.D.	21±9	N.D.	12±2	33±6	N.D.
Hg	41±7	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	Gain	43±23	Gain
Li	Gain	Gain	Gain	78±3	90±7	N.D.	92±2	Gain	21±8	N.D.
Mn	92±25	93±3	77±7	89±10	96±3	61±2	87±7	63±6	44±4	77±5
Ni	89±6	58±5	65±10	Gain	Gain	51±5	N.D.	93±1	51±5	41±9
Pb	Gain	93±11	98±1	Gain	N.D.	67±5	99±2	Gain	38±14	N.D.
Sb	Ind	Ind	Gain	Ind	Ind	Ind	Ind	Ind	Ind	Ind
Se	N.D.	Ind	N.D.	N.D.	Ind	Ind	Ind	<85	Ind	Ind
Sn	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind
V	Gain	93±11	N.D.	N.D.	N.D.	36±7	N.D.	Gain	N.D.	38±21
Zn	95±1	N.D.	84±1	82±4	55±18	68±4	50±21	90±1	67±2	56±14

[a] "Ind" means the element was too low to be determined in the starting coal.

[b] "N.D." means either no removal occurred or the statistical error was too large to determine the removal.

widely mixed results which are unexplained on the basis of either analysis error or likely sources of contamination.

In summary, the trace element studies to date have shown that the analysis procedures are generally acceptable with the exception of procedures for V and Pb. The studies also indicate that As, Be, Cr, Mn, Ni, Se and Zn are amenable to removal by the Meyers Process in at least some American coals. Seven elements - Ag, Be, Cd, Hg, Sb, Se and Sn - were not generally present in the coals at levels exceeding 3 ppm. Three elements, B, Cu and F, do not appear to be removed in significant amounts by the Meyers Process.

5.0 ACKNOWLEDGMENTS

The following TRW personnel deserve acknowledgment: W.P. Kendrick and D. Kilday for experimental assistance; E.A. Burns and R.J. Ottinger for technical assistance; J.L. Blumenthal and B. Dubrow for managerial assistance; and C.M. Yarden for report coordination.

The Program Manager for this study at the Systems Group of TRW Inc., was Robert A. Meyers and the monitoring Project Officer for this Environmental Protection Agency contract was Lloyd Lorenzi, Jr. Appreciation is expressed to Mr. Lorenzi for his guidance and encouragement. Messrs. I. Foster and R. Kaplan of the Commercial Testing and Engineering Company (Chicago, Illinois) deserve special recognition for their cooperation in expediting coal sampling and analyses for TRW at CT&E.

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7.0 GLOSSARY OF ABBREVIATIONS AND SYMBOLS

Abbreviations

Abs	absolute
ASTM	American Society for Testing and Materials
btu	British Thermal Unit
cal	calories
eq	equation
Exp.	experiment
Kcal	kilocalories
ml	milliliter
ppm	parts per million
Rxn.	reaction
wt	weight

Symbols

C	concentration.
Δ	difference in quantity following delta.
μ	micron.
$\underline{M}$	molarity.
mM	millimole.
$\underline{N}$	normality.
P	total pressure, atmospheres.
R	gas constant, cal/mole, °K.
S	sulfur.
S^o	elemental sulfur.
S_o	organic sulfur.
S_p	pyritic sulfur.
S_t	total sulfur.
SO_4	sulfate.

Symbols (cont'd)

σ	standard deviation.
T	absolute temperature, °K.
t	time, hours (leaching)-minutes (regeneration).
V	volume.
W_p	pyrite concentration in coal, wt%.
Y	ferric ion to total iron ratio.

8.0 UNIT CONVERSION TABLE

To Convert From	To	Multiply By
btu	calories	252.0
feet	meters	0.3048
gallons	liters	3.785
inches	centimeters	2.540
ounces	grams	28.35
pounds	grams	453.6
pounds	kilograms	0.4536
temp (°F -32	temp (°C)	0.5556
tons	kilograms	907.2

9.0 APPENDICES

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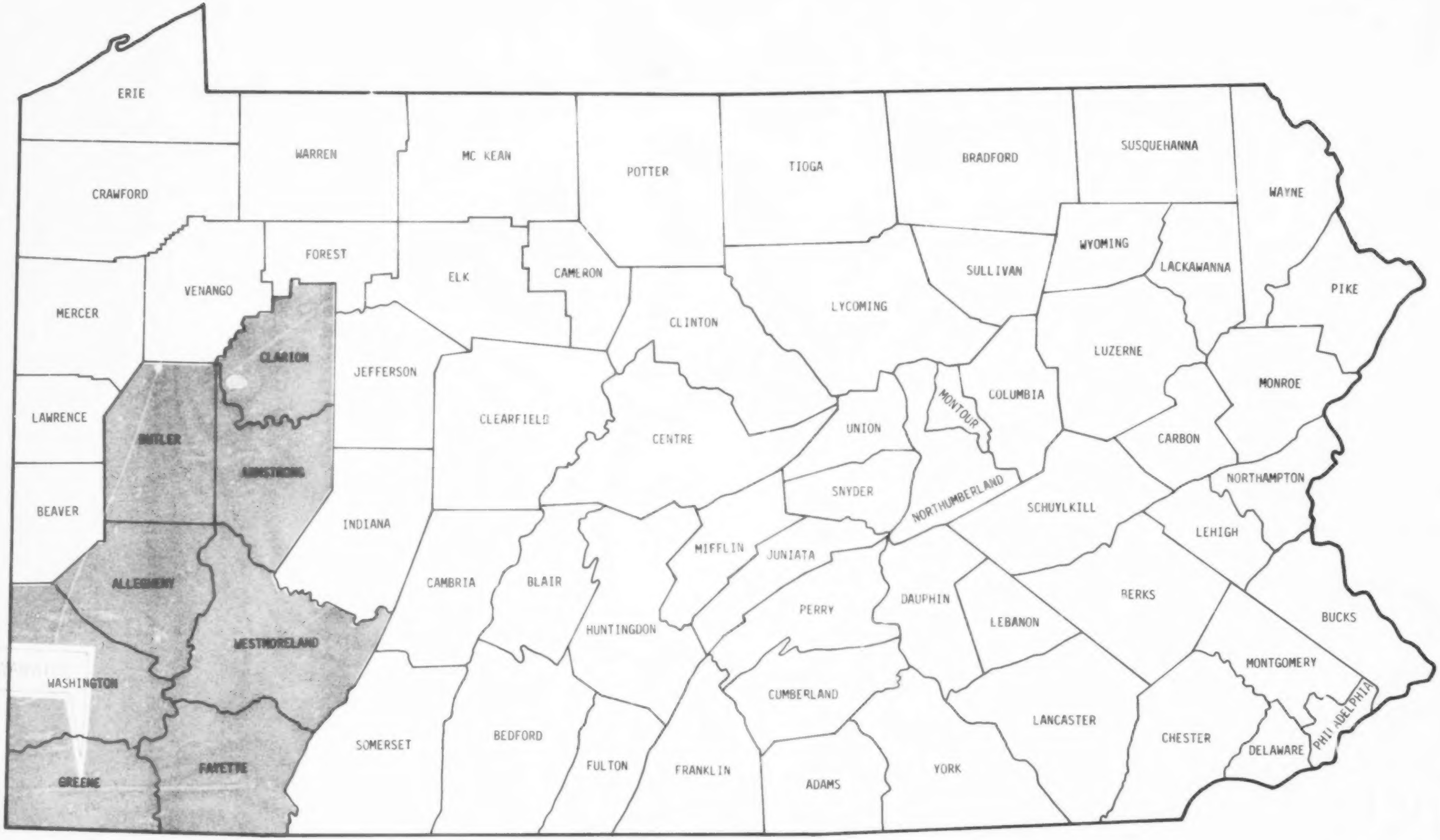
Appendix A

Seam Extent and Sample Location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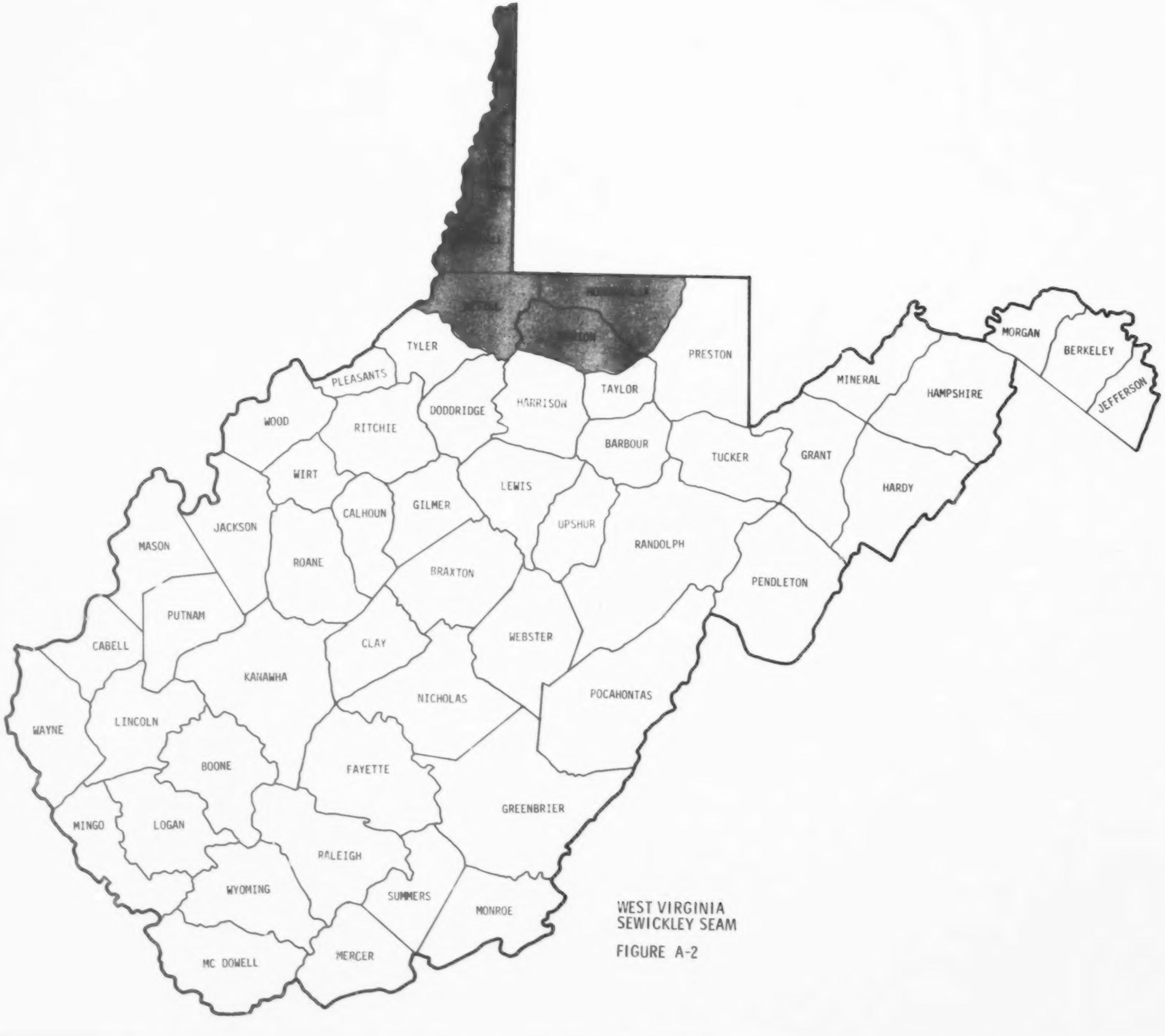
PENNSYLVANIA
SEWICKLEY SEAM

FIGURE A-1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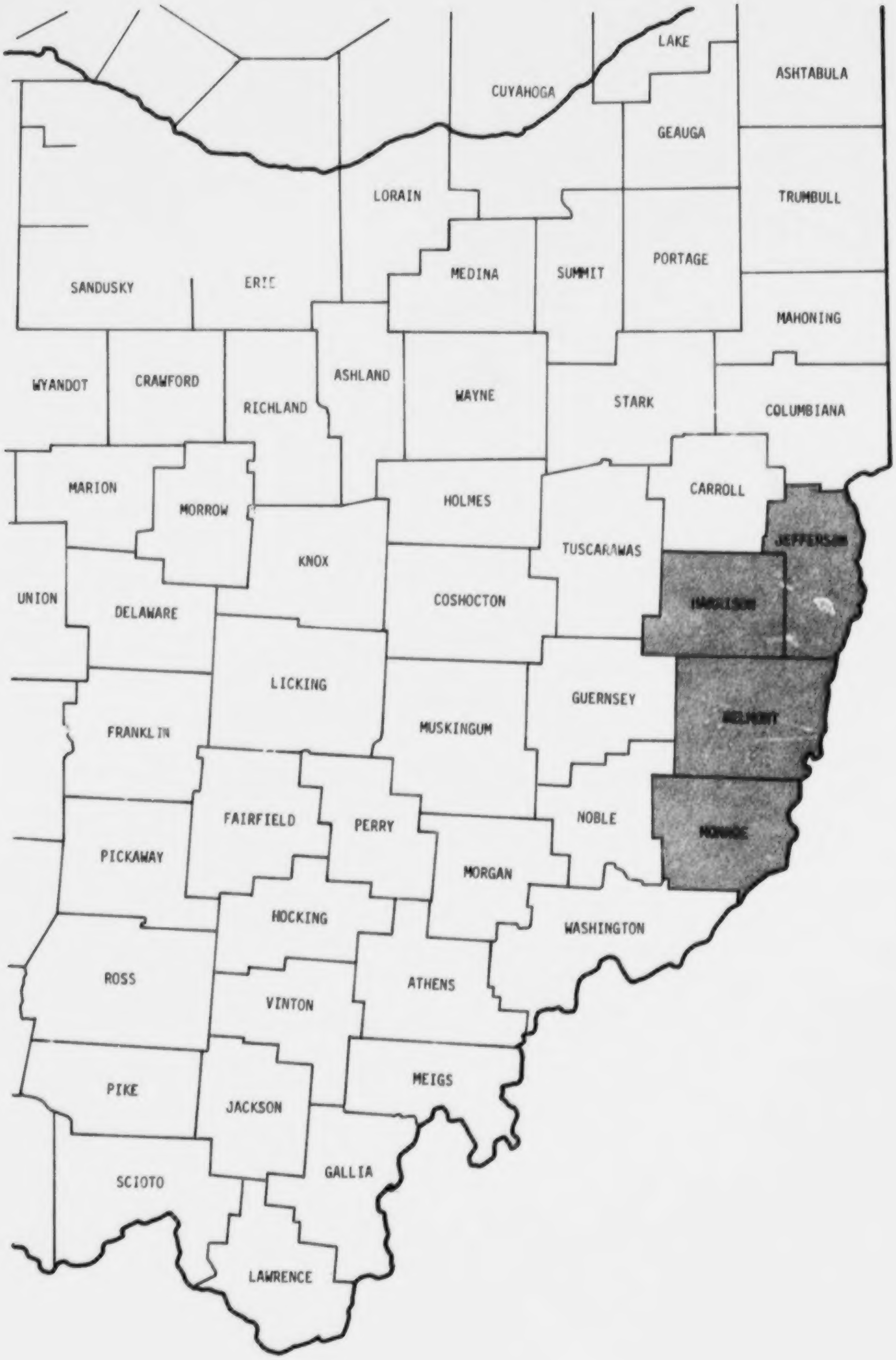
WEST VIRGINIA
SEWICKLEY SEAM

FIGURE A-2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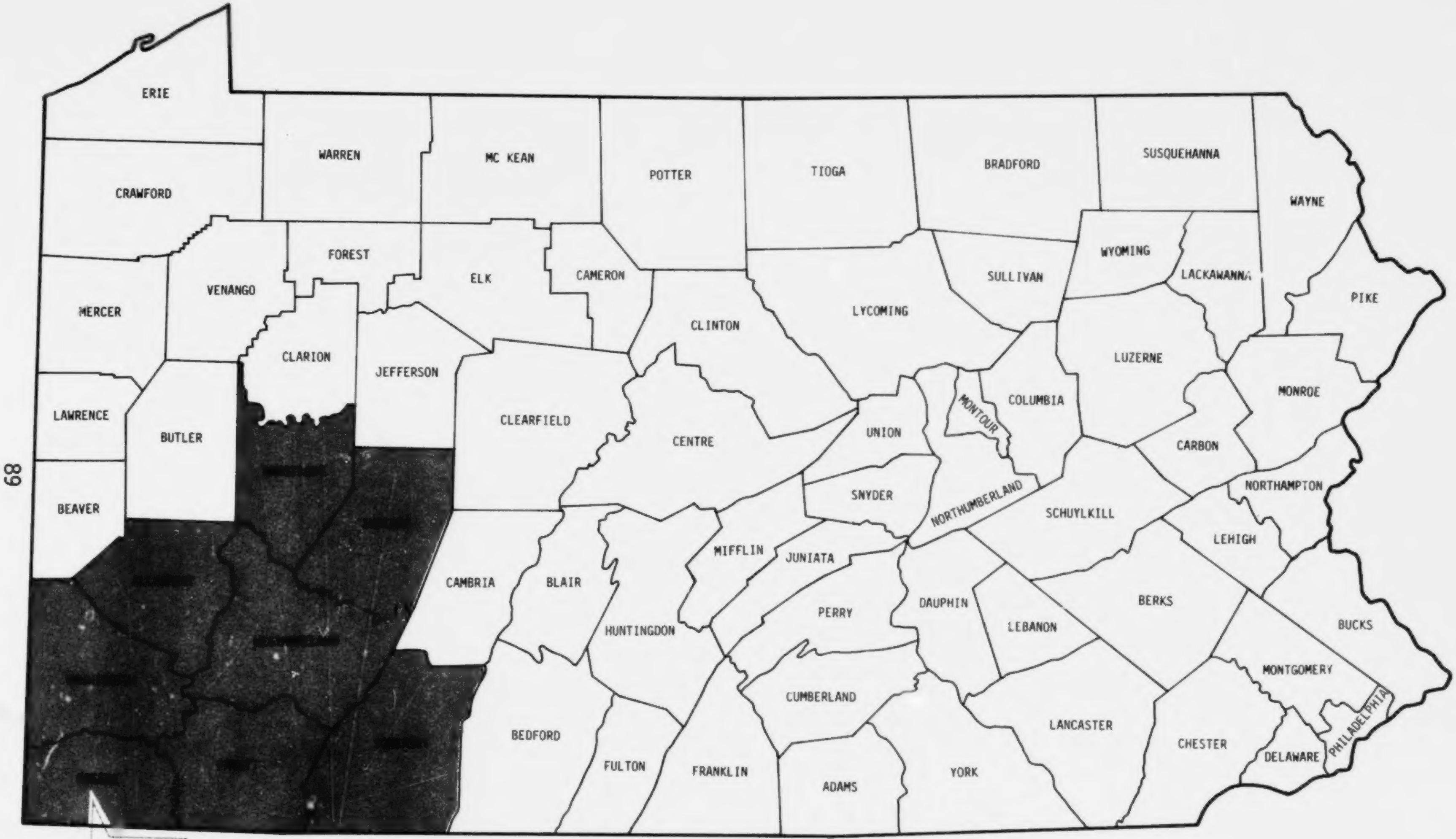
OHIO
SEWICKLEY SEAM

FIGURE A-3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PENNSYLVANIA
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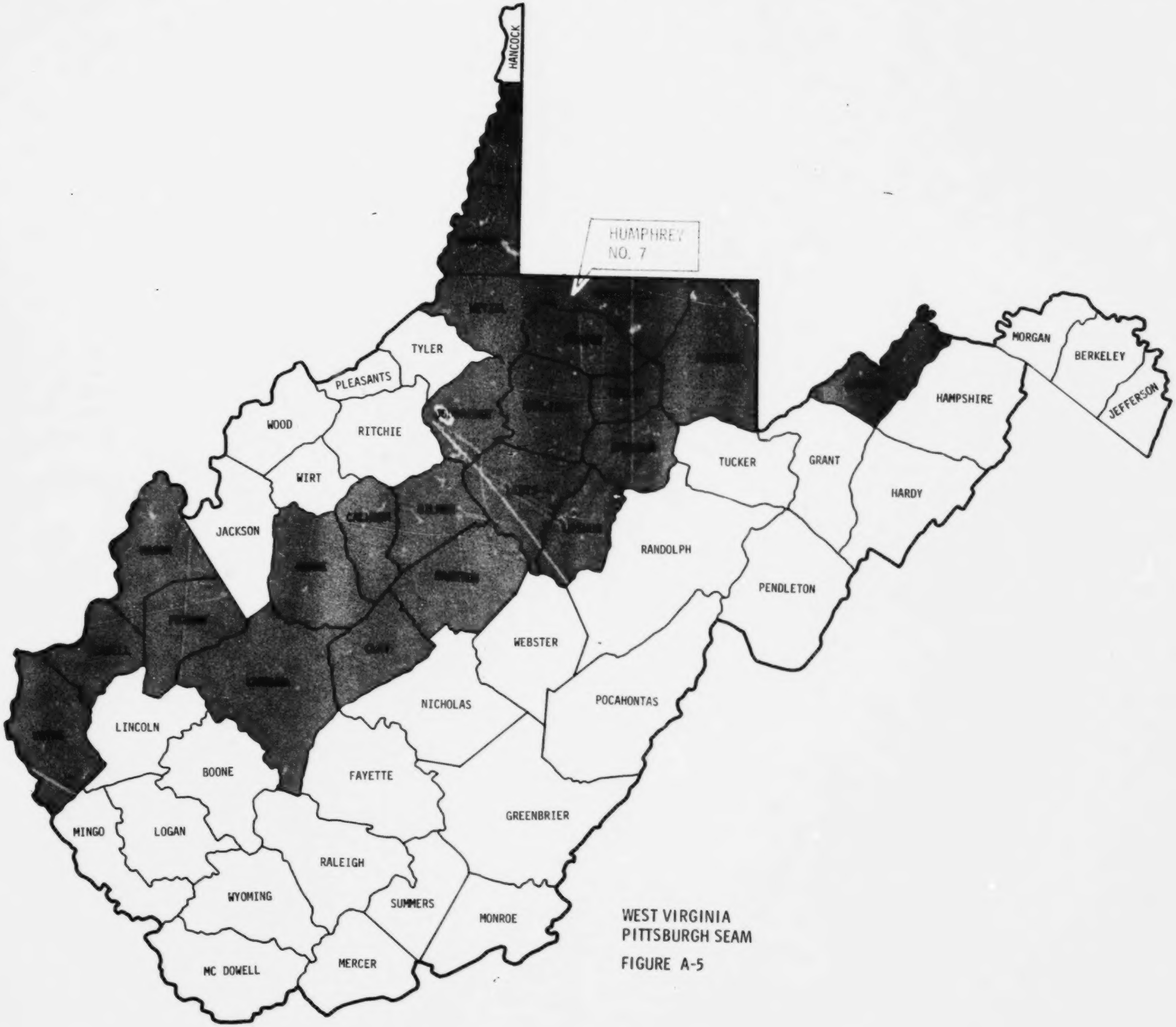
FIGURE A-4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WEST VIRGINIA
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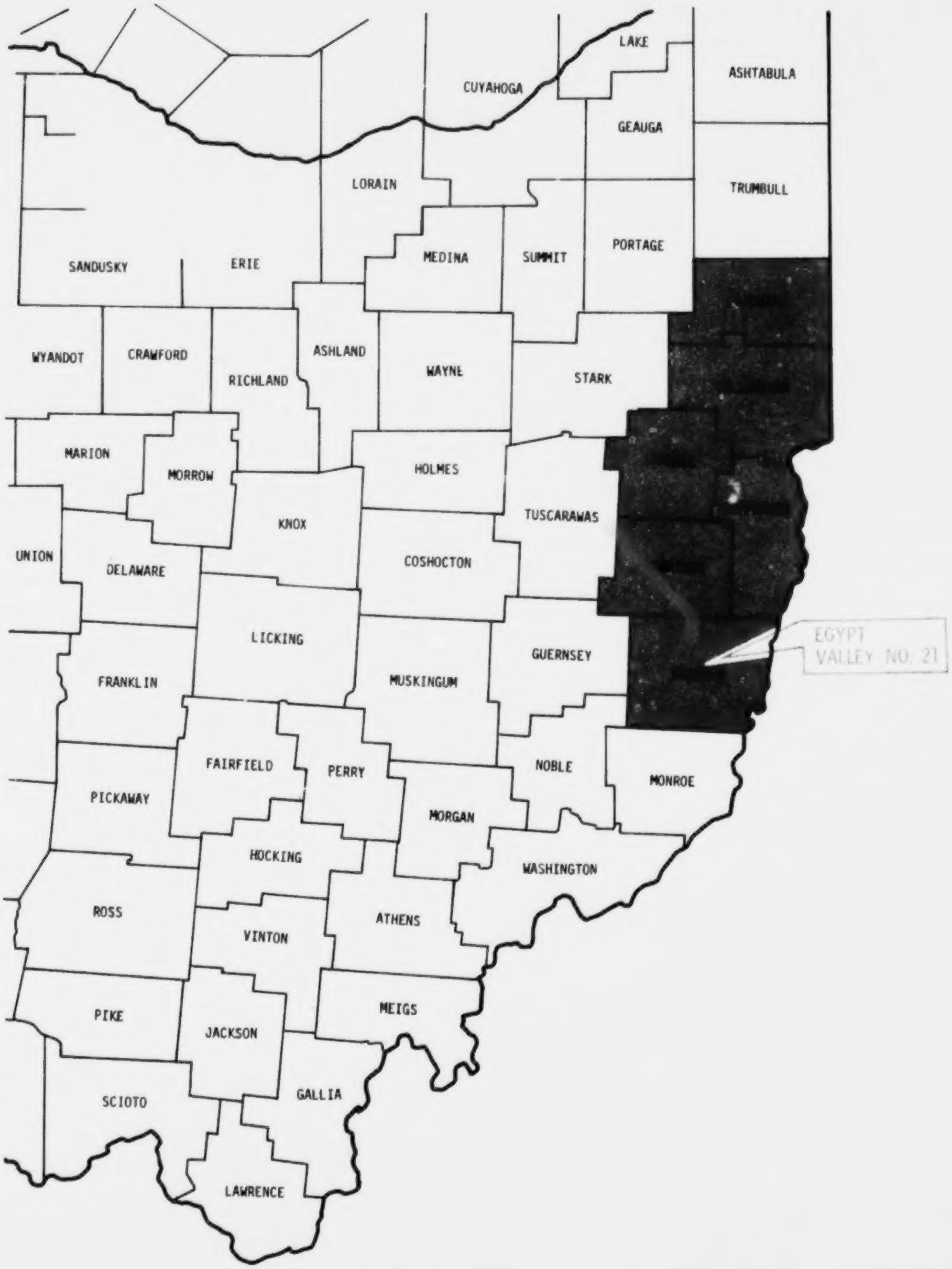
FIGURE A-5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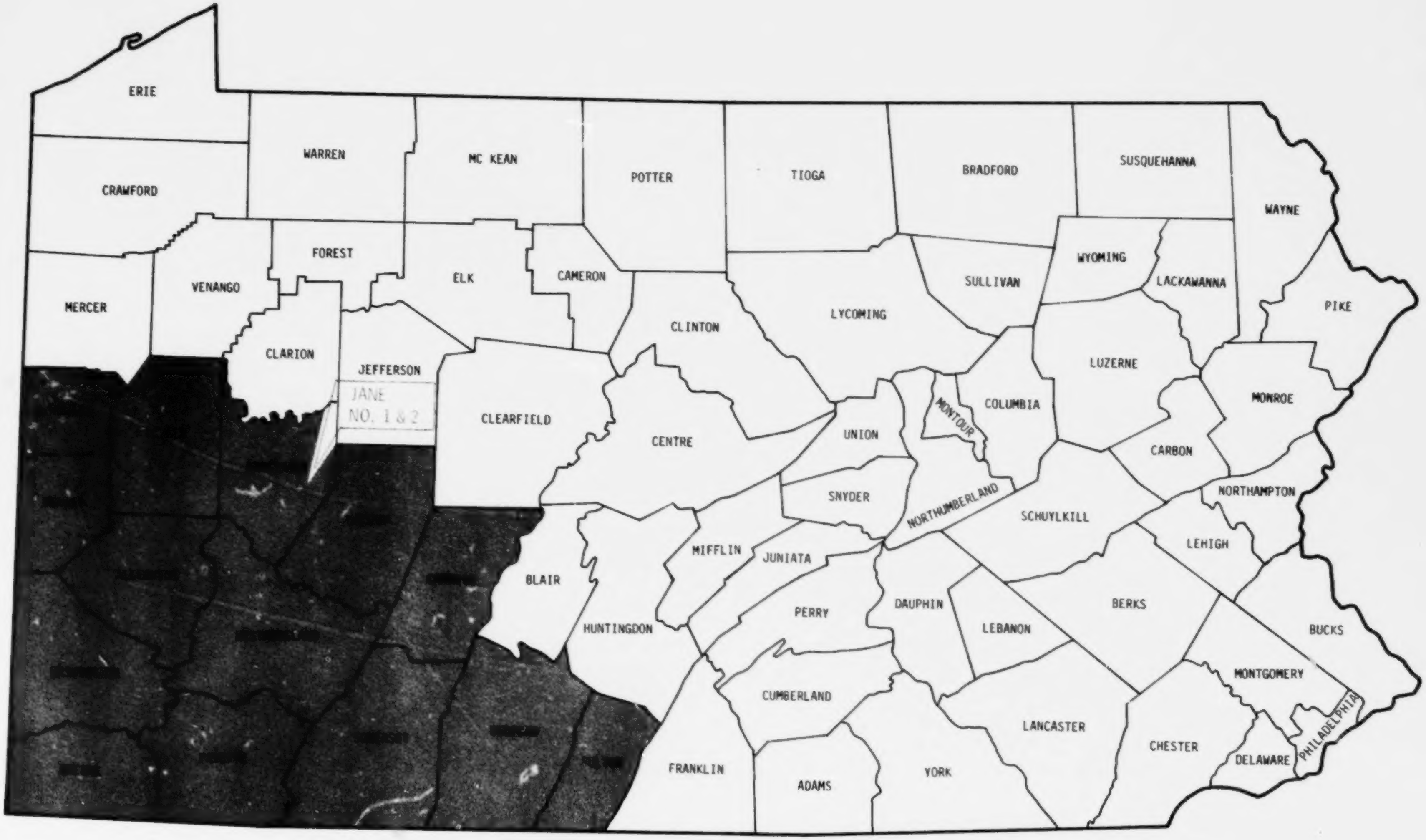
OHIO
PITTSBURGH SEAM
FIGURE A-6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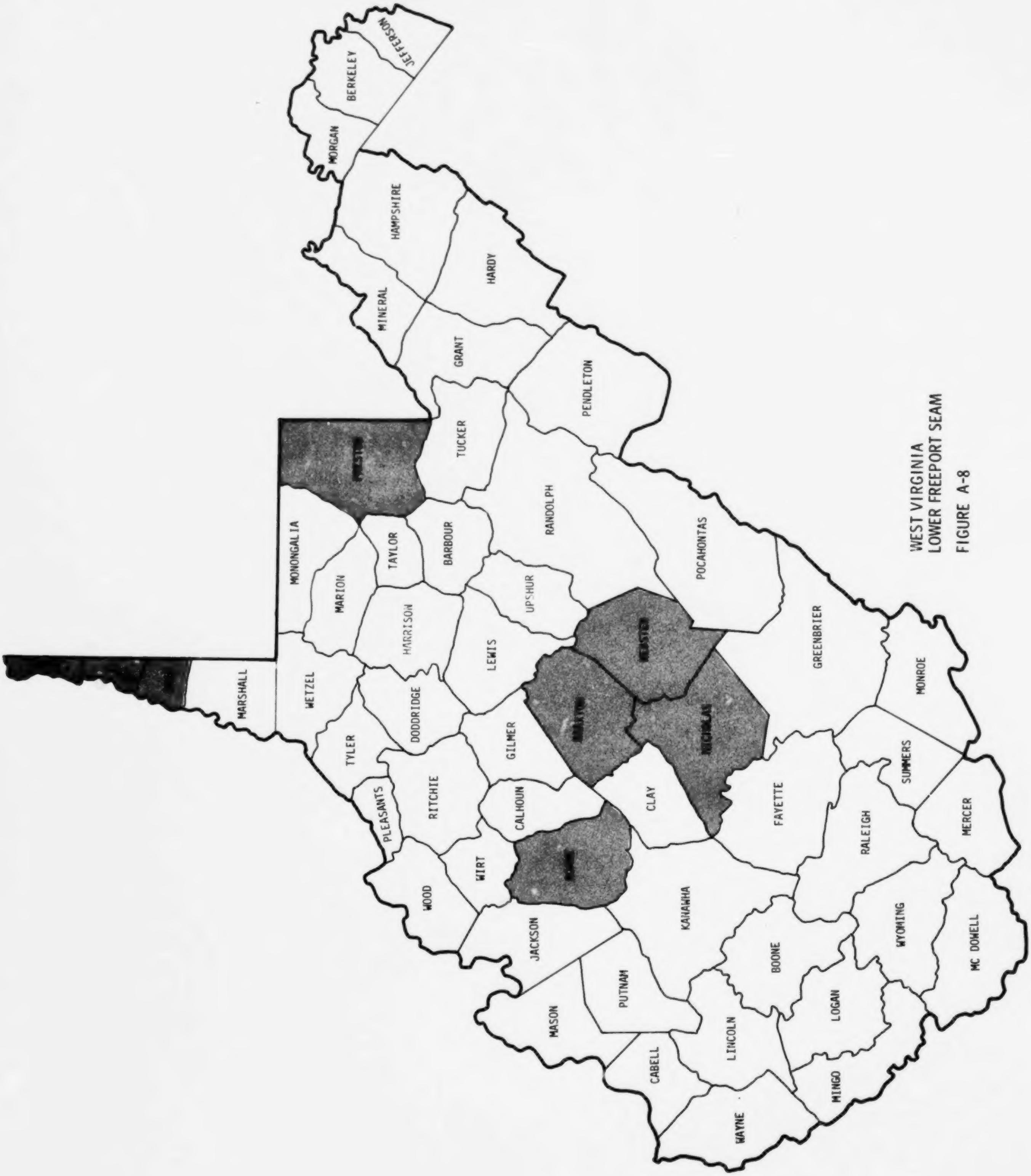
PENNSYLVANIA
LOWER FREEPORT SEAM

FIGURE A-7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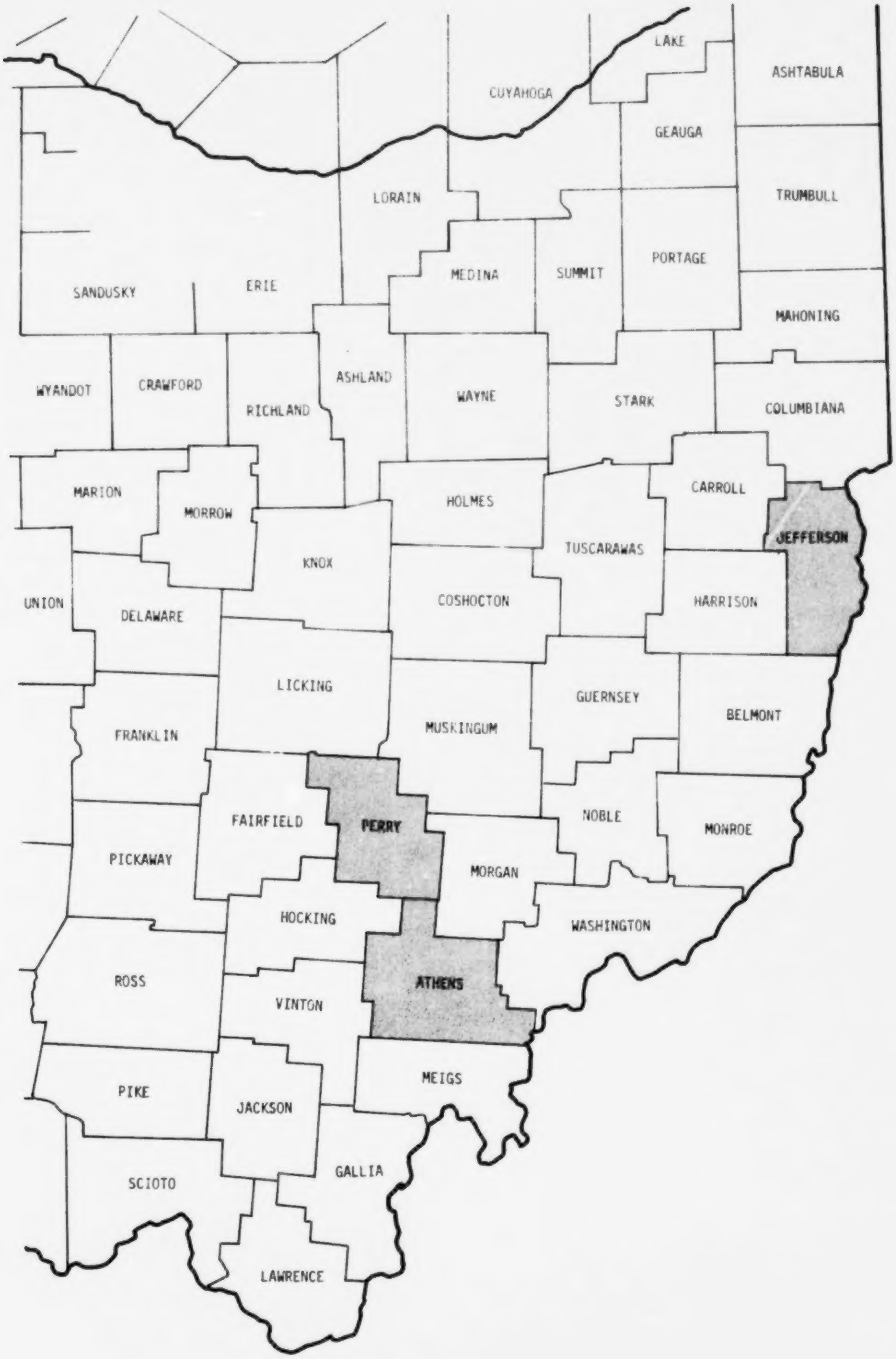
WEST VIRGINIA
LOWER FREEPORT SEAM

FIGURE A-8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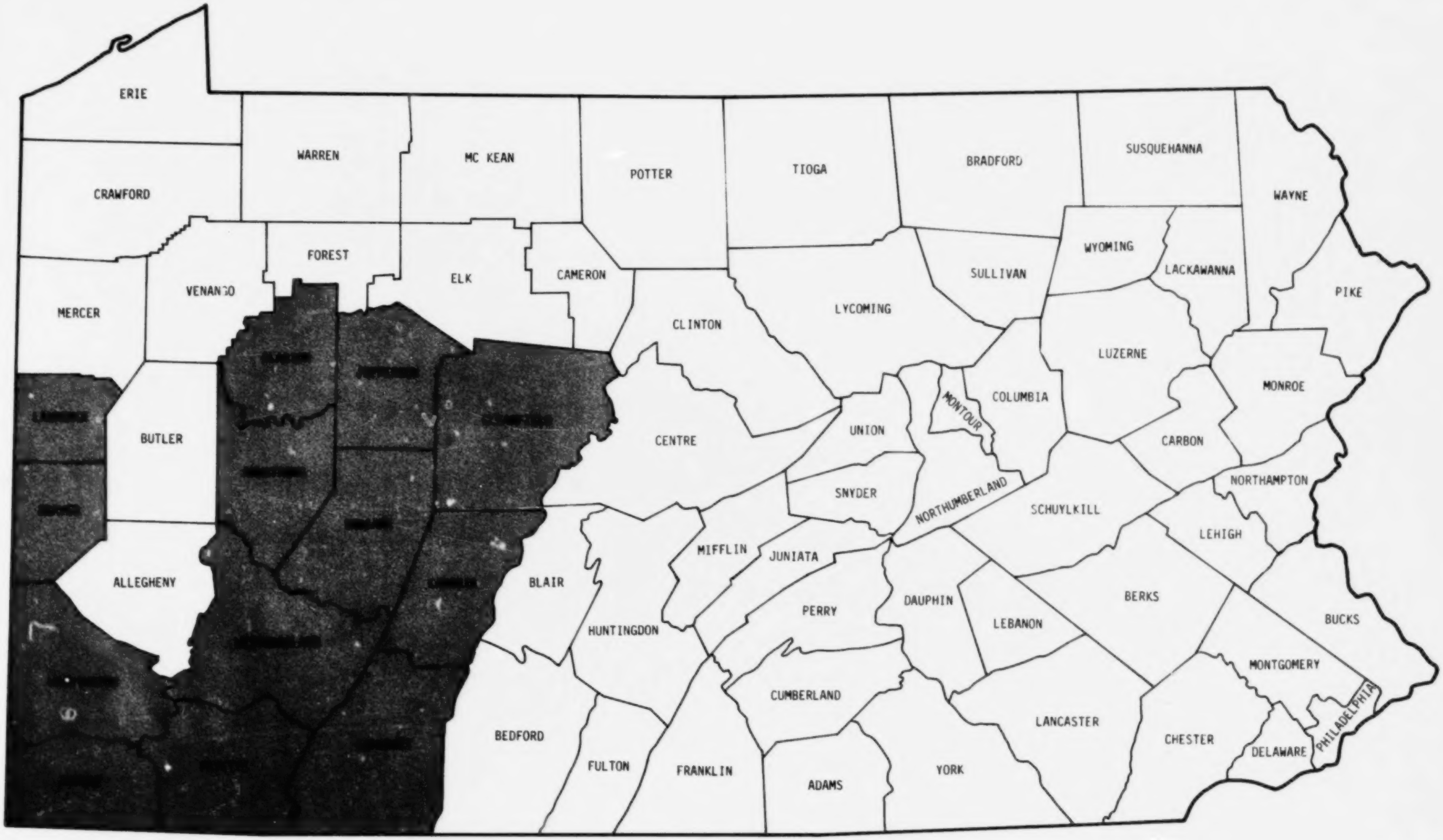
OHIO
LOWER FREEPORT SEAM

FIGURE A-9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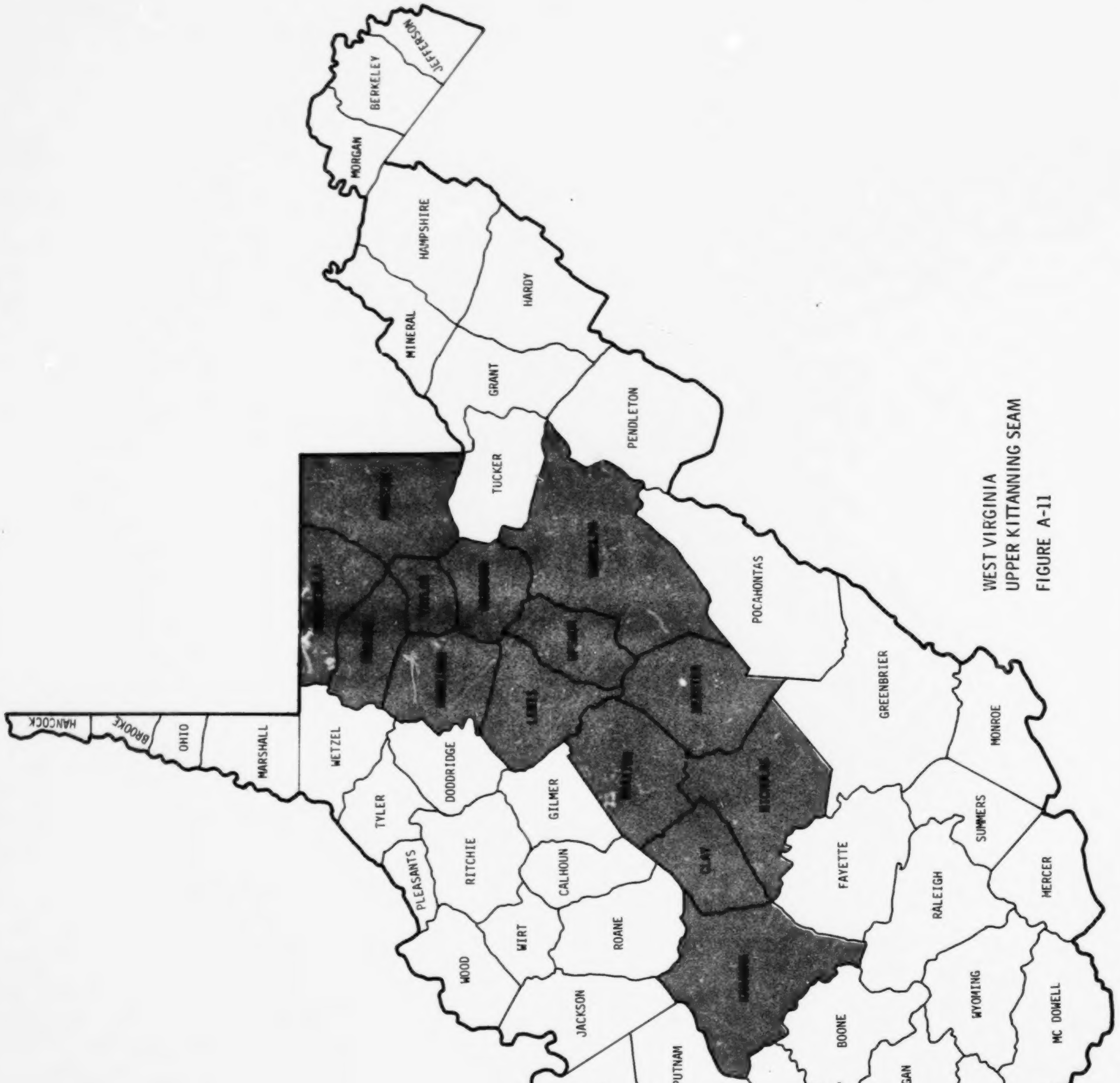
PENNSYLVANIA
UPPER KITTANNING SEAM

FIGURE A-10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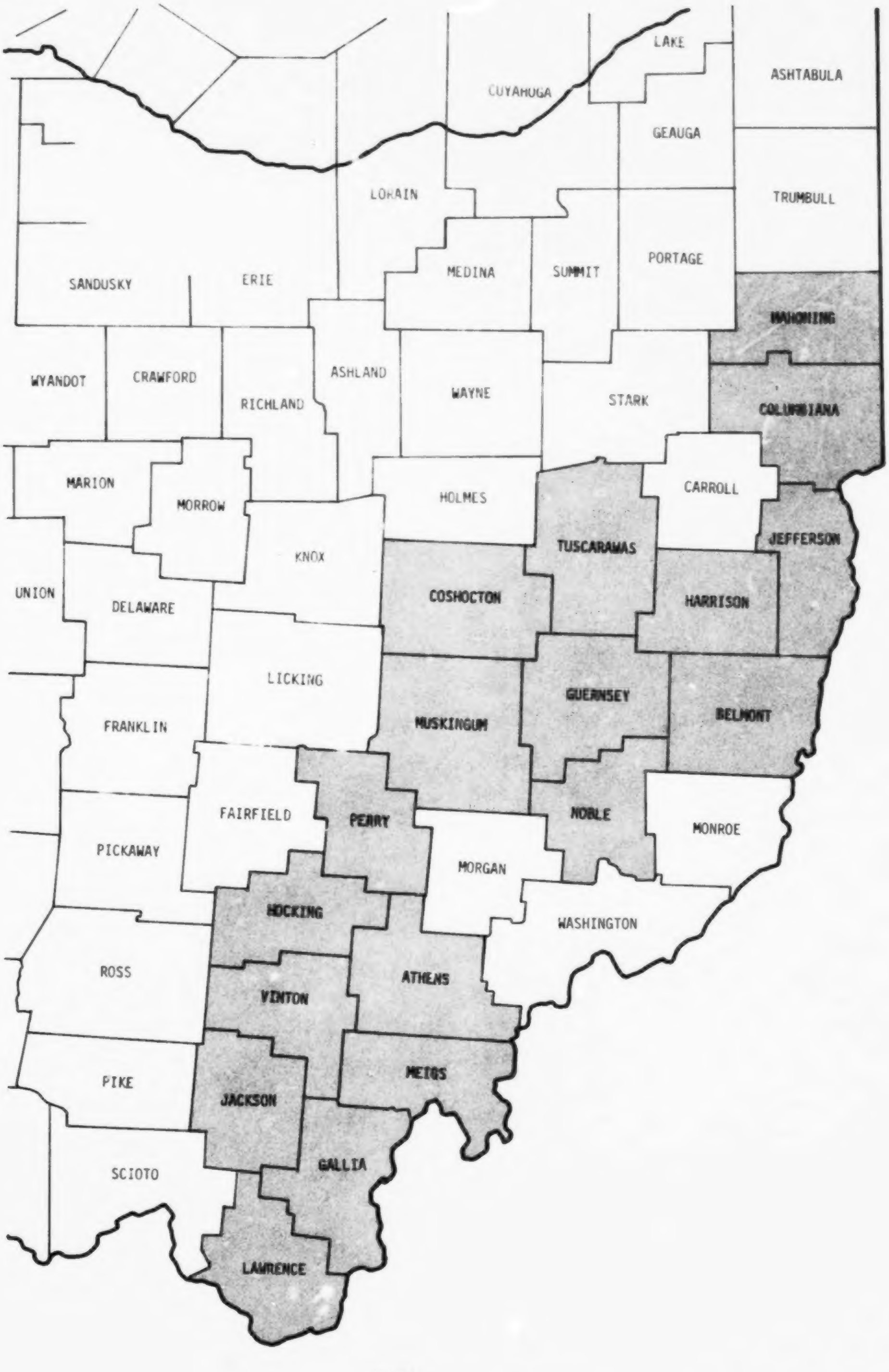
WEST VIRGINIA
UPPER KITTANNING SEAM
FIGURE A-11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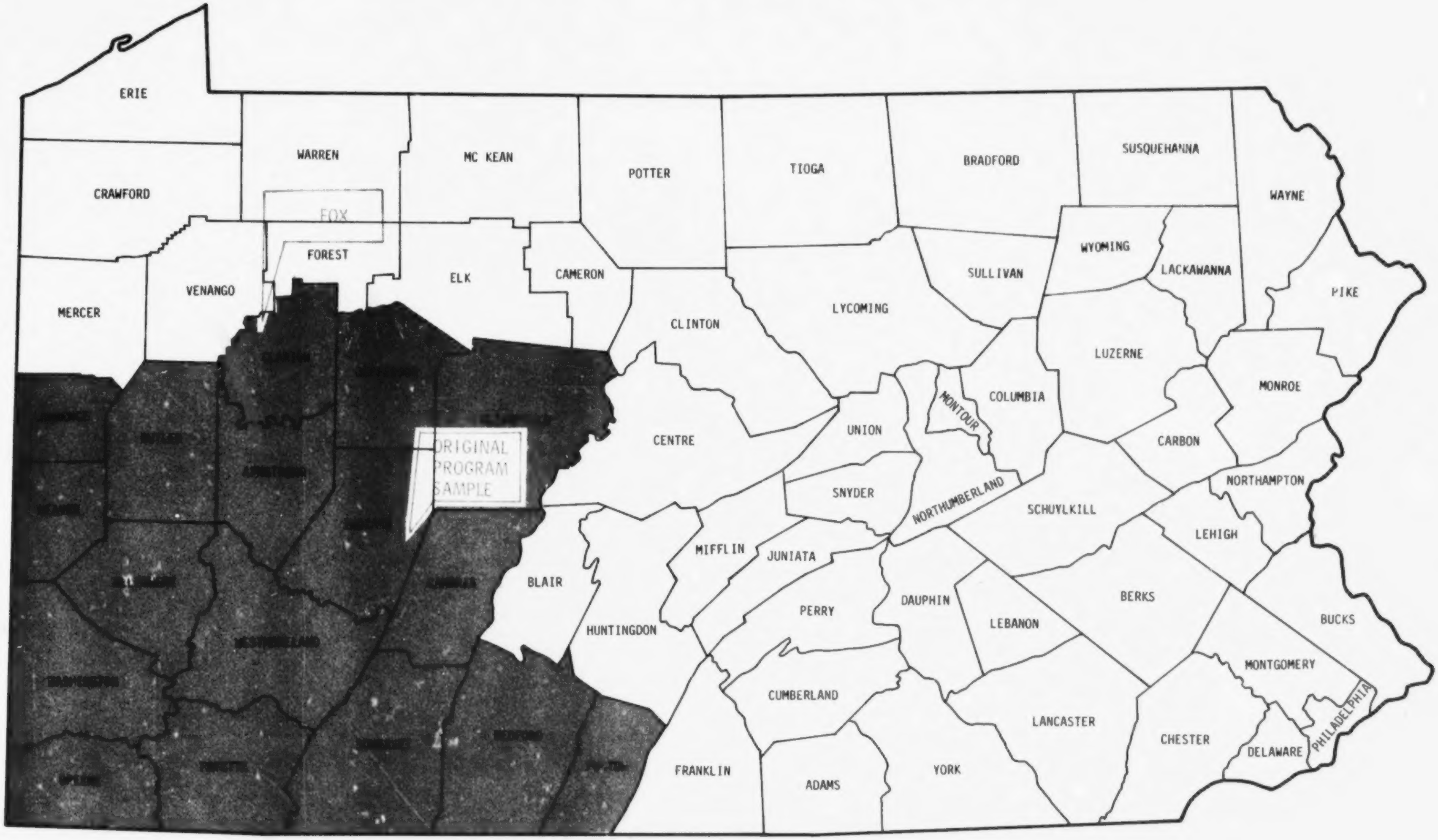
FAIRFIELD
PERRY
NOBLE
MONROE
PICKAWAY
MORGAN
HOCKING
WASHINGTON
ROSS
VINTON
ATHENS
PIKE
JACKSON
MEIGS
SCIOTO
GALLIA
LAWRENCE

OHIO
UPPER KITTANNING SEAM

FIGURE A-12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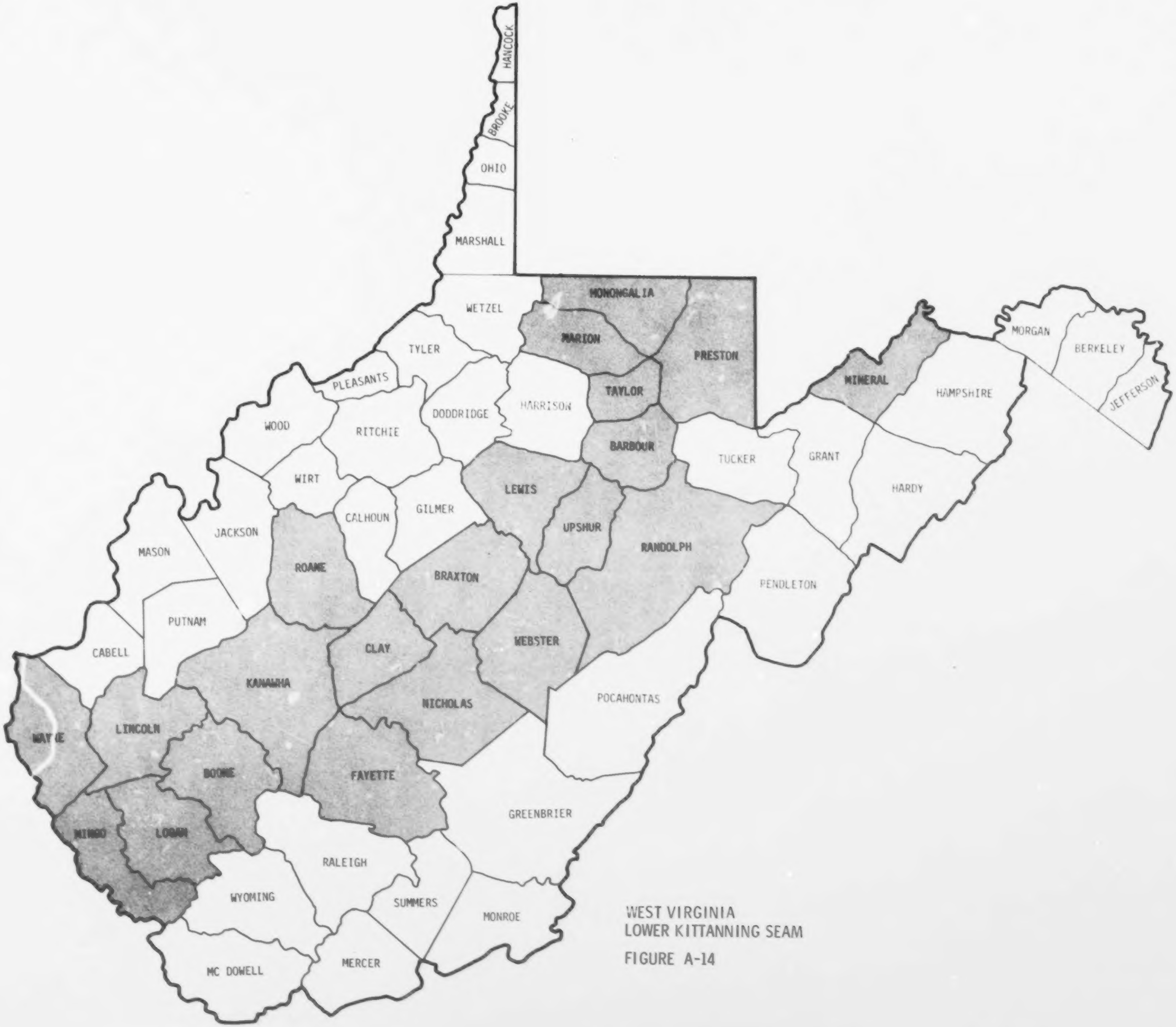
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOX
FOREST
ELK
CAMERON
MERCER
VENANGO
WYOMING
LACKAWANNA
PIKE
SULLIVAN
LYCOMING
CLINTON
LUZERNE
MONROE
COLUMBIA
MONTOUR
UNION
CENTRE
CARBON
ORIGINAL PROGRAM SAMPLE
SNYDER
NORTHUMBERLAND
SCHUYLKILL
NORTHAMPTON
LEHIGH
MIFFLIN
JUNIATA
BLAIR
PERRY
DAUPHIN
BERKS
BUCKS
LEBANON
HUNTINGDON
MONTGOMERY
CUMBERLAND
LANCASTER
CHESTER
DELAWARE
PHILADELPHIA
FRANKLIN
ADAMS
YORK

PENNSYLVANIA
LOWER KITTANNING SEAM
FIGURE A-13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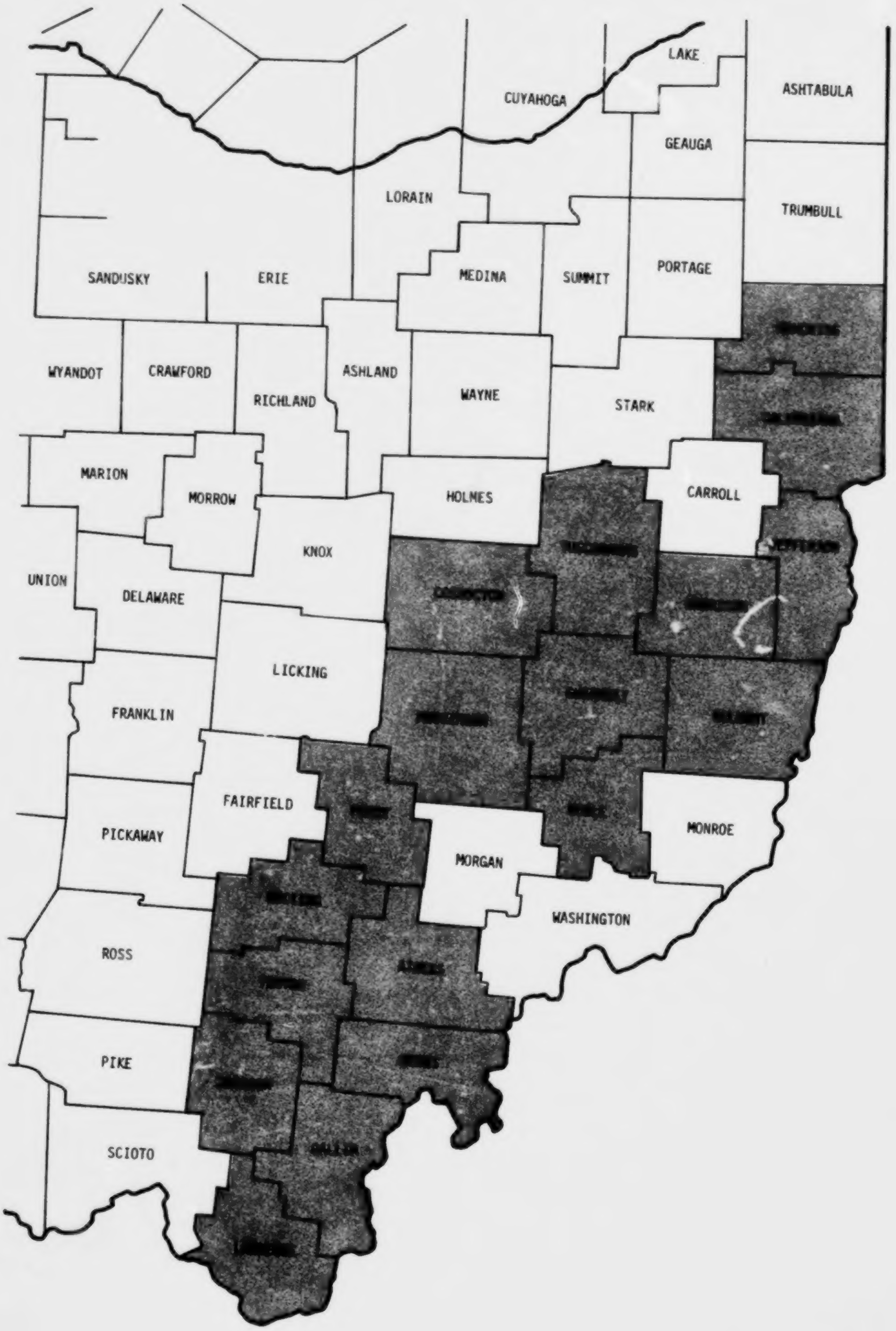
BROOKE
OHIO
MARSHALL
WETZEL
MONONGALIA
MARION
PRESTON
TYLER
PLEASANTS
TAYLOR
MINERAL
MORGAN
BERKELEY
JEFFERSON
HAMPSHIRE
WOOD
RITCHIE
DODDRIDGE
HARRISON
BARBOUR
TUCKER
GRANT
HARDY
WIRT
CALHOUN
GILMER
LEWIS
UPSHUR
RANDOLPH
JACKSON
MASON
ROANE
BRAXTON
PENDLETON
PUTNAM
CABELL
CLAY
WEBSTER
KANAWHA
NICHOLAS
POCAHONTAS
WAYNE
LINCOLN
BOONE
FAYETTE
GREENBRIER
MINGO
LOGAN
RALEIGH
WYOMING
SUMMERS
MONROE
MC DOWELL
MERCER

WEST VIRGINIA
LOWER KITTANNING SEAM

FIGURE A-14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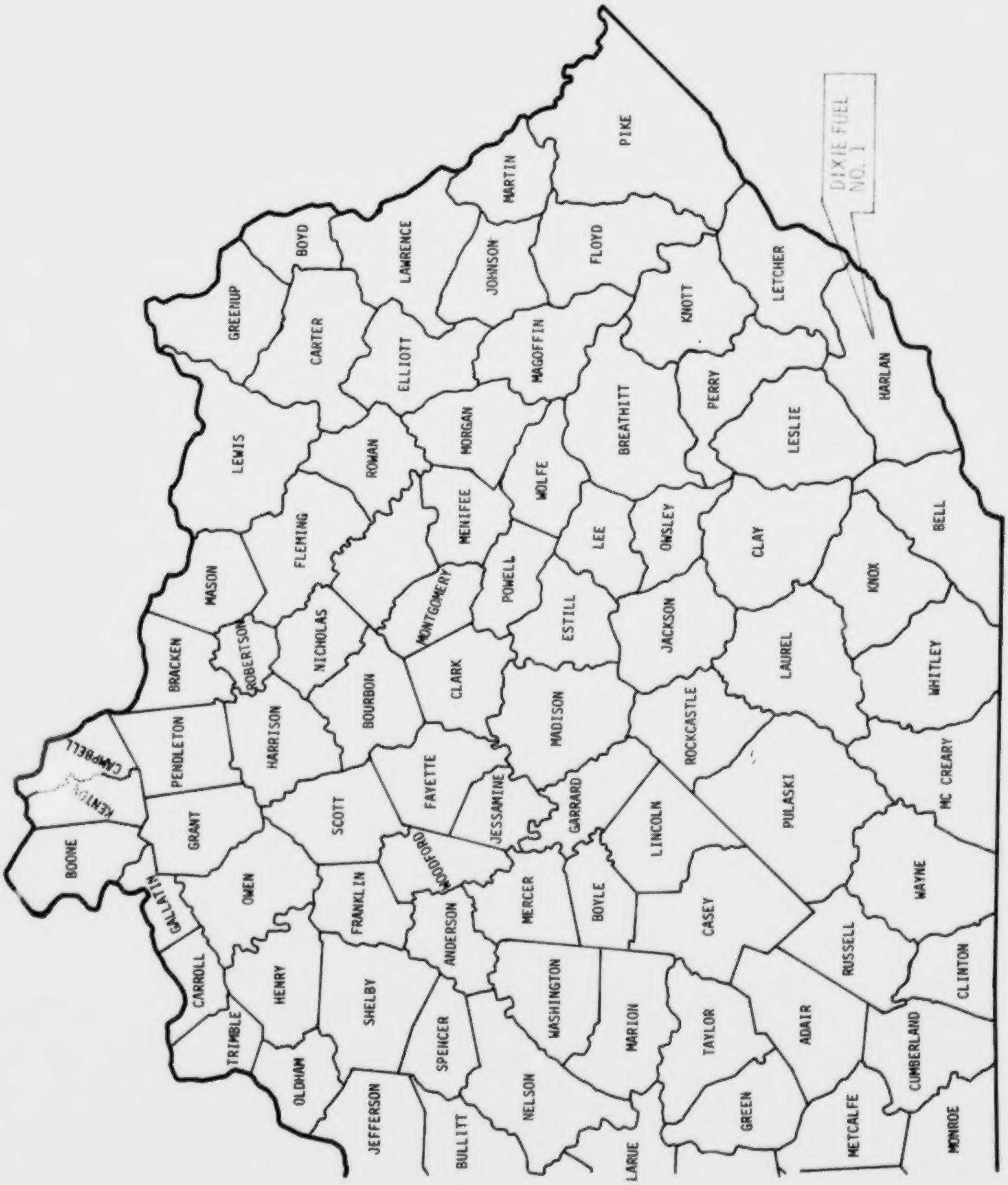
ASHTABULA
GEAUGA
LORAIN
TRUMBULL
SANDUSKY
ERIE
MEDINA
SUMMIT
PORTAGE
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
CARROLL
KNOX
JEFFERSON
UNION
DELAWARE
COSHOCTON
LICKING
FRANKLIN
FAIRFIELD
PICKAWAY
MORGAN
MONROE
WASHINGTON
ROSS
PIKE
SCIOTO

OHIO
LOWER KITTANNING SEAM

FIGURE A-15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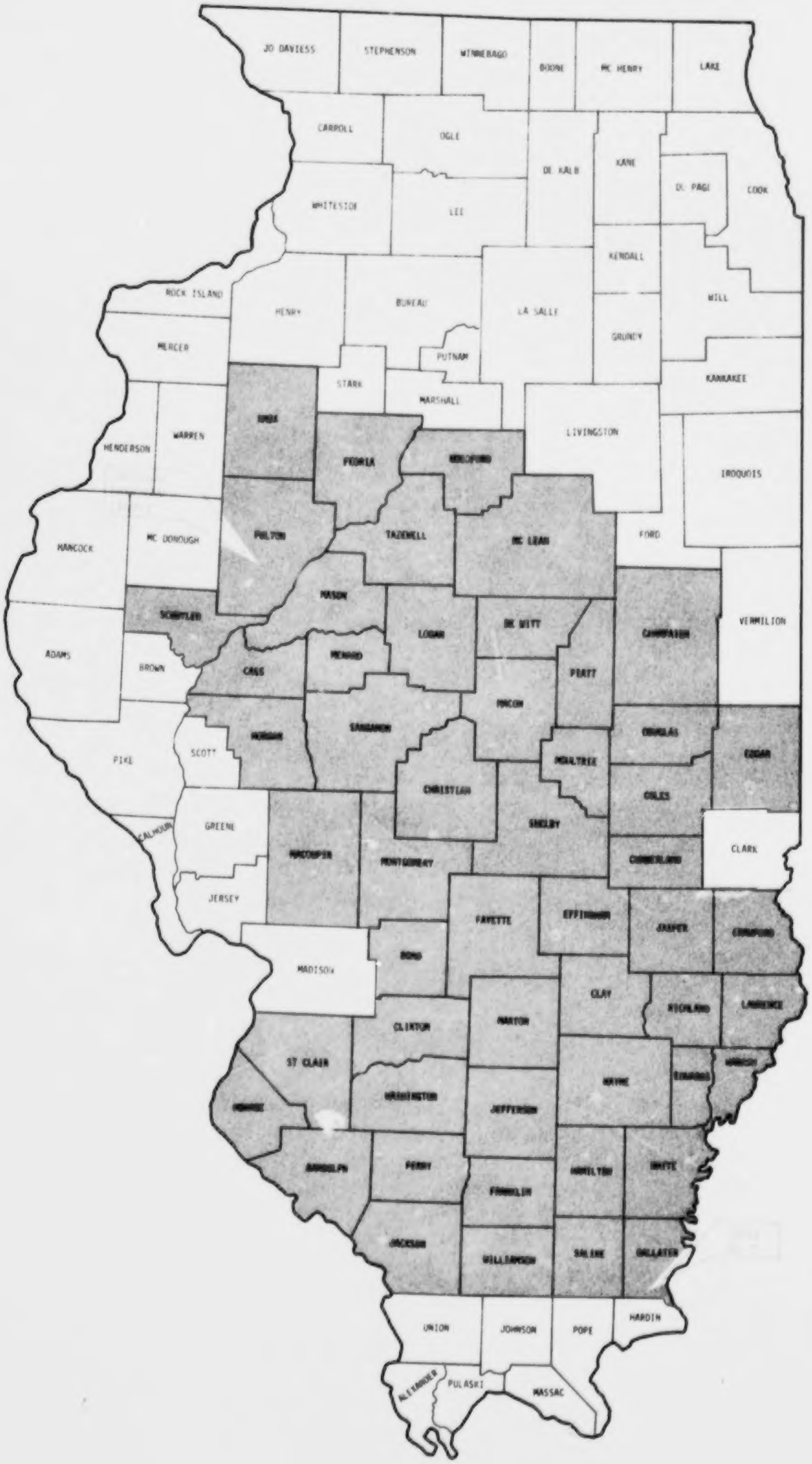
MARTIN
FLOYD
JOHNSON
LAWRENCE
BOYD
GREENUP
CARTER
ELLIOTT
MAGOFFIN
KNOTT
LETCHER
HARLAN
PERRY
LESLIE
BREATHITT
MORGAN
ROWAN
LEWIS
FLEMING
MENIFEE
WOLFE
LEE
OWSLEY
CLAY
BELL
KNOX
MASON
ROBERTSON
NICHOLAS
MONTGOMERY
POWELL
ESTILL
JACKSON
LAUREL
WHITLEY
BRACKEN
CAMPBELL
KENTON
BOONE
PENDLETON
HARRISON
BOURBON
CLARK
MADISON
ROCKCASTLE
PULASKI
MC CREARY
GRANT
SCOTT
FAYETTE
JESSAMINE
GARRARD
LINCOLN
WAYNE
GALLATIN
OWEN
FRANKLIN
WOODFORD
MERCER
BOYLE
CASEY
RUSSELL
CLINTON
CARROLL
HENRY
SHELBY
ANDERSON
WASHINGTON
MARION
TAYLOR
ADAIR
CUMBERLAND
TRIMBLE
OLDHAM
SPENCER
NELSON
GREEN
METCALFE
MONROE
JEFFERSON
BULLITT
LARUE

EASTERN KENTUCKY
MASON SEAM
FIGURE A-16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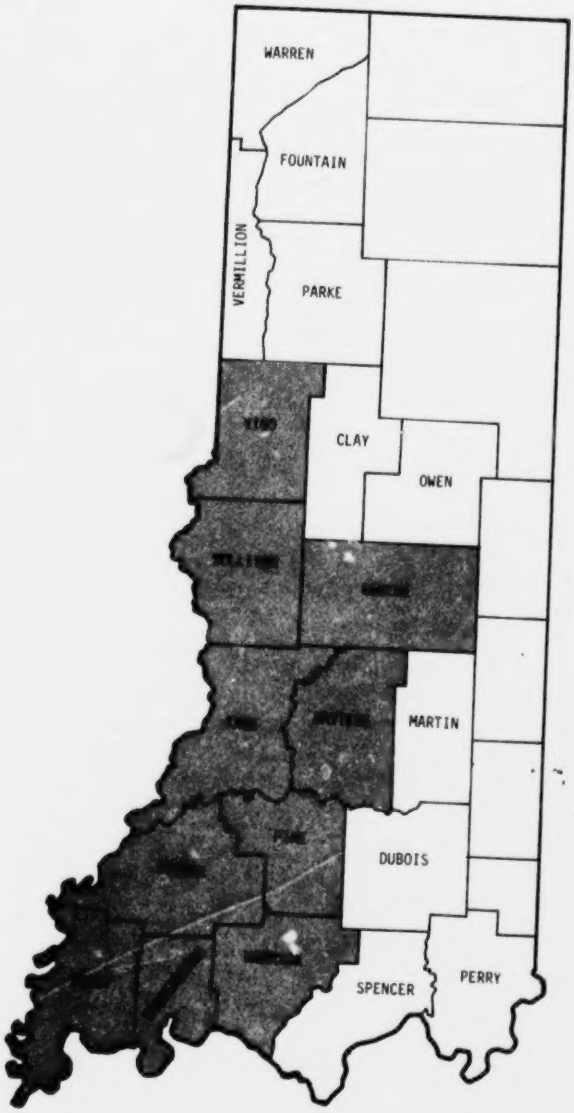
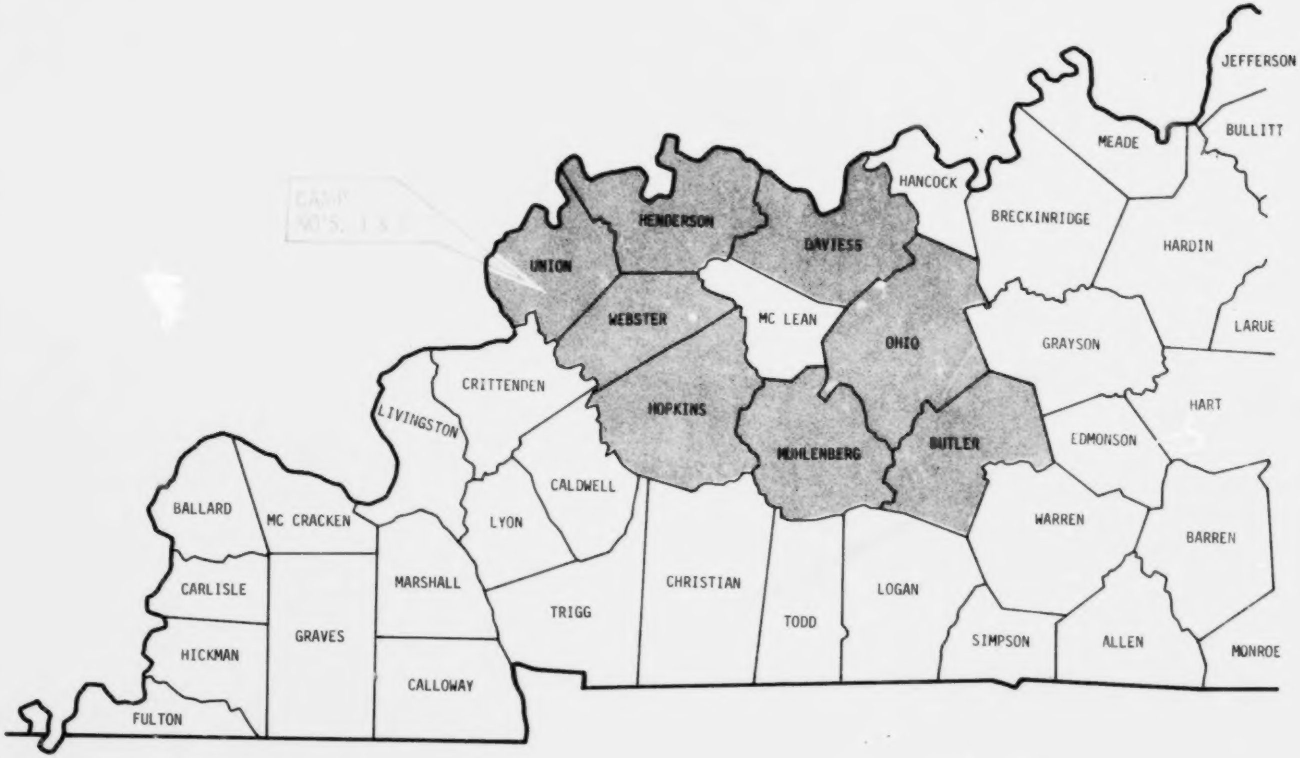
STEPHENSON
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
DU PAGE
COOK
WHITESIDE
LEE
KENDALL
ROCK ISLAND
HENRY
BUREAU
LA SALLE
WILL
MERCER
PUTNAM
GRUNDY
STARK
KANKAKEE
MARSHALL
KNOX
HENDERSON
WARREN
PEORIA
WOODFORD
LIVINGSTON
IROQUOIS
HANCOCK
MC DONOUGH
FULTON
TAZEWELL
MC LEAN
FORD
MASON
SCHUYLER
LOGAN
DE WITT
CHAMPAIGN
VERMILION
ADAMS
BROWN
CASS
MENARD
PIATT
SANGAMON
MACON
MORGAN
DOUGLAS
PIKE
SCOTT
EDGAR
MOULTRIE
CHRISTIAN
COLES
SHELBY
CALHOUN
GREENE
CLARK
MACOUPIN
MONTGOMERY
CUMBERLAND
JERSEY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
BOND
MADISON
CLAY
RICHLAND
LAWRENCE
CLINTON
MARION
ST CLAIR
WABASH
EDWARDS
WAYNE
WASHINGTON
MONROE
JEFFERSON
RANDOLPH
PERRY
HAMILTON
WHITE
FRANKLIN
JACKSON
SALINE
WILLIAMSON
GALLATIN
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

ILLINOIS
NO. 5 - HARRISBURG - SPRINGFIELD SEAM

FIGURE A-17


WARREN
FOUNTAIN
VERMILLION
PARKE
CLAY
OWEN
MARTIN
DUBOIS
SPENCER
PERRY

INDIANA
SPRINGFIELD - NO.V SEAM
FIGURE A-18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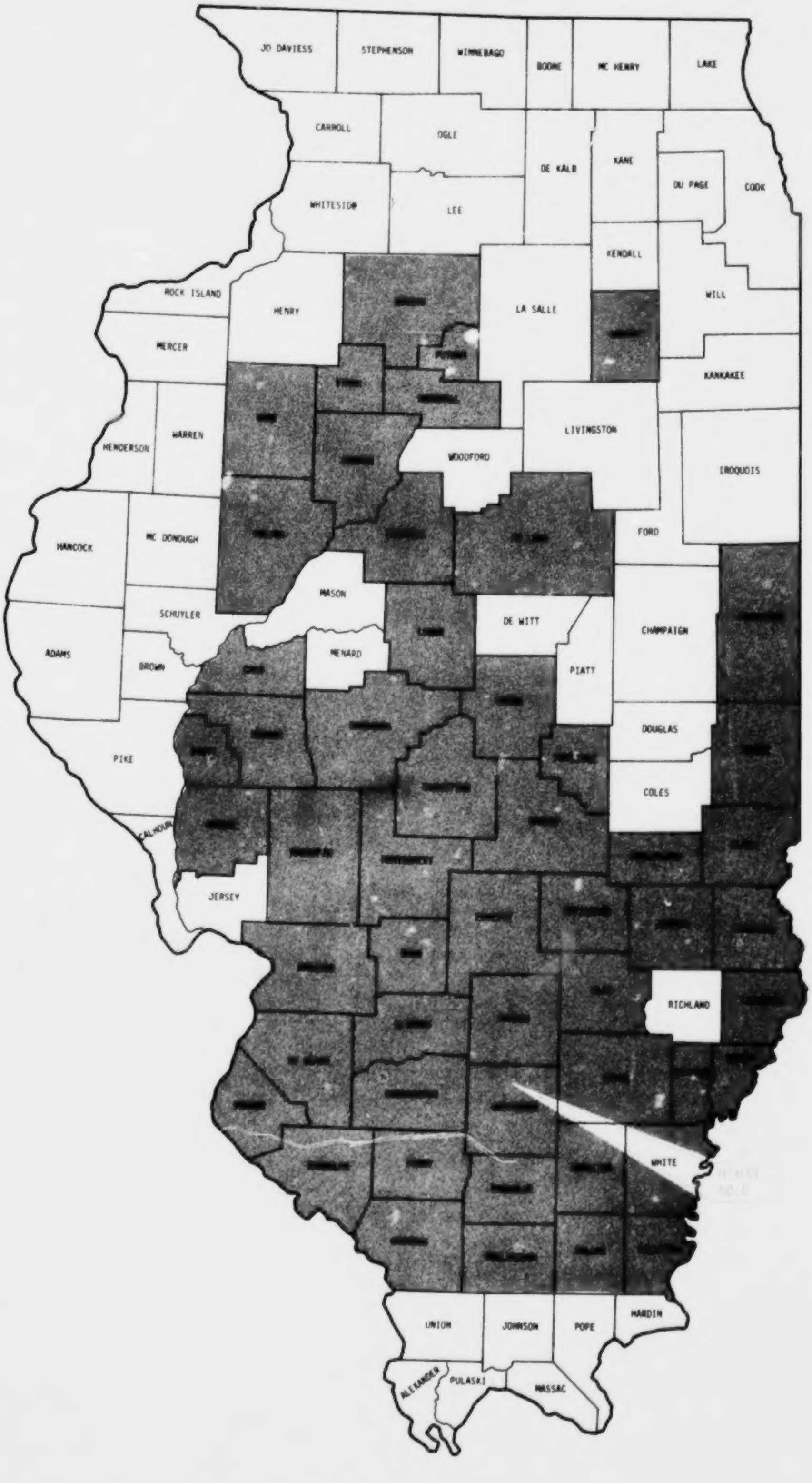
BULLITT
MEADE
HANCOCK
BRECKINRIDGE
HARDIN
HENDERSON
DAVIESS
UNION
WEBSTER
MC LEAN
OHIO
GRAYSON
LARUE
CRITTENDEN
HOPKINS
LIVINGSTON
MUHLENBERG
BUTLER
HART
EDMONSON
CALDWELL
BALLARD
MC CRACKEN
LYON
WARREN
BARREN
CARLISLE
MARSHALL
CHRISTIAN
LOGAN
TRIGG
TODD
SIMPSON
ALLEN
MONROE
HICKMAN
GRAVES
CALLOWAY
FULTON

WESTERN KENTUCKY
NO. 9 SEAM

FIGURE A-19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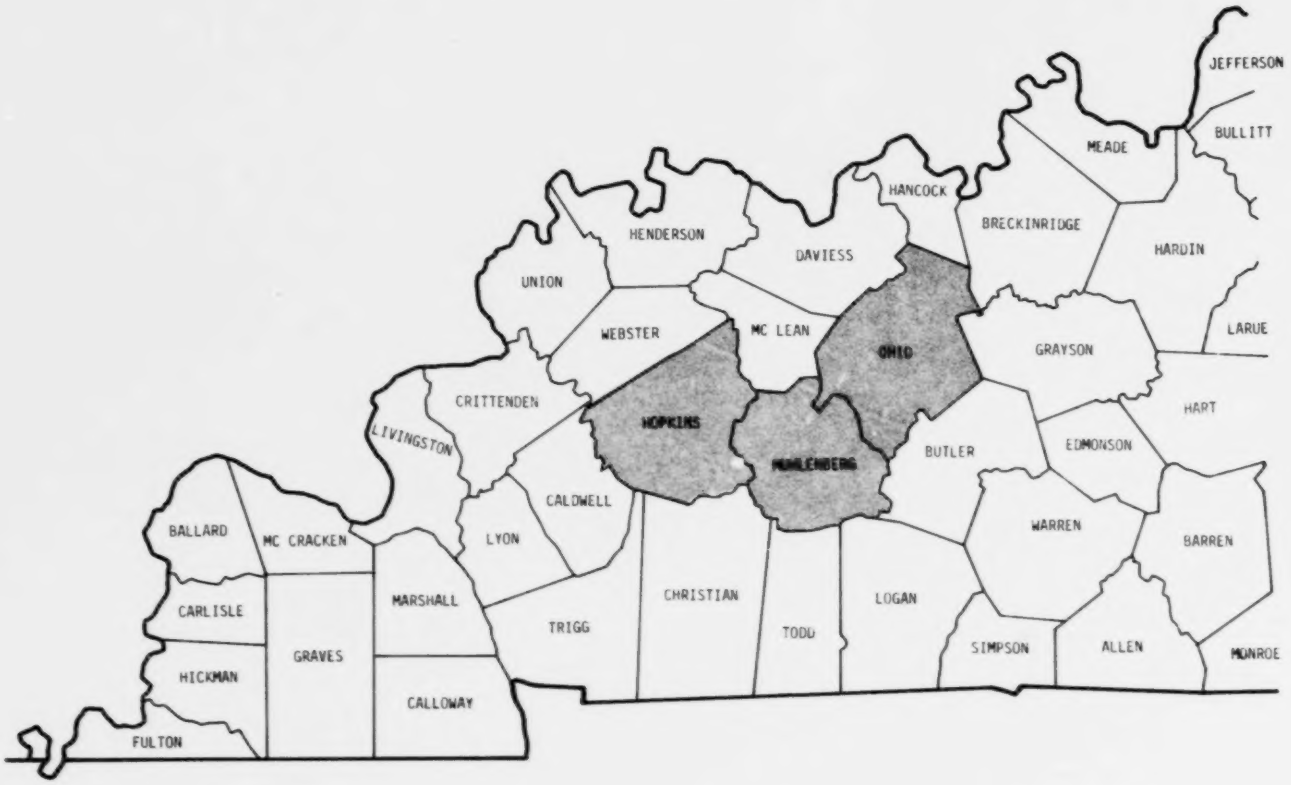
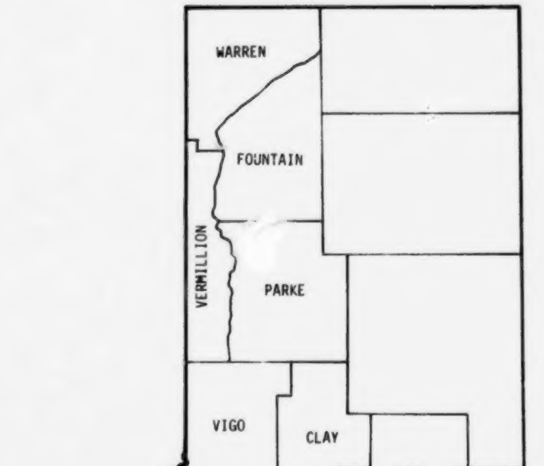
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
DU PAGE
COOK
WHITESIDE
LEE
KENDALL
ROCK ISLAND
HENRY
LA SALLE
WILL
MERCER
KANKAKEE
HENDERSON
WARREN
WOODFORD
LIVINGSTON
IROQUOIS
HANCOCK
MC DONOUGH
FORD
MASON
SCHUYLER
DE WITT
CHAMPAIGN
ADAMS
BROWN
MENARD
PIATT
DOUGLAS
PIKE
COLES
CALHOUN
JERSEY
RICHLAND
WHITE
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

ILLINOIS
HERRIN NO. 6 SEAM
FIGURE A-20


JEFFERSON
BULLITT
MEADE
HANCOCK
BRECKINRIDGE
HARDIN
HENDERSON
DAVIESS
UNION
LARUE
MC LEAN
WEBSTER
OHIO
GRAYSON
HART
CRITTENDEN
HOPKINS
LIVINGSTON
MUHLENBERG
BUTLER
EDMONSON
CALDWELL
BALLARD
MC CRACKEN
LYON
WARREN
BARREN
CARLISLE
MARSHALL
CHRISTIAN
LOGAN
TRIGG
TODD
SIMPSON
ALLEN
MONROE
GRAVES
HICKMAN
CALLOWAY
FULTON

WESTERN KENTUCKY
NO. 11 SEAM

FIGURE A-21


WARREN
FOUNTAIN
VERMILLION
PARKE
VIGO
CLAY
OWEN
GREENE
DAVIESS
MARTIN
DUBOIS
SPENCER
PERRY

INDIANA
HYMERA - NO. VI SEAM
FIGURE NO. A-22

Appendix B

Ranking of Treated and Untreated Coals

Table B-1

Coal Ranking Data-Untreated Coal

Reproduced from best available copy.

```
EDNA-UNTREATED
MOISTURE= 8.41%, MOISTBTU= 11216
SULFUR=  .75%, ASH=  9.13%, BTU= 12246
FIXED CARBON= 50.22%, VOLATILE MATTER= 40.65%
DRY MINERAL MATTER FREE FIXED CARBON= 55.84%
DRY MINERAL MATTER FREE VOLATILE MATTER= 44.16%
DRY MINERAL MATTER FREE BTU= 13602
MOIST MINERAL MATTER FREE BTU= 12458
EPA STANDARD-% SULFUR= .73%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C


NAVAJO-UNTREATED
MOISTURE=11.07%, MOISTBTU=  8937
SULFUR=  .81%, ASH= 25.29%, BTU= 10050
FIXED CARBON= 39.20%, VOLATILE MATTER= 35.51%
DRY MINERAL MATTER FREE FIXED CARBON= 54.09%
DRY MINERAL MATTER FREE VOLATILE MATTER= 45.91%
DRY MINERAL MATTER FREE BTU= 13849
MOIST MINERAL MATTER FREE BTU= 12316
EPA STANDARD-% SULFUR= .60%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C


BELLE AYR-UNTREATED
MOISTURE=19.14%, MOISTBTU=  9731
SULFUR=  .76%, ASH=  7.55%, BTU= 12034
FIXED CARBON= 45.34%, VOLATILE MATTER= [illegible].11%
DRY MINERAL MATTER FREE FIXED CARBON= 49.47%
DRY MINERAL MATTER FREE VOLATILE MATTER= 50.53%
DRY MINERAL MATTER FREE BTU= 13111
MOIST MINERAL MATTER FREE BTU= 10601
EPA STANDARD-% SULFUR= .72%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C,AGGLOMERATING
CLASS III-1,SUBBITUMINOUS A,NONAGGLOMERATING
```

```
COLSTRIP-UNTREATED
MOISTURE=20.41%, MOISTBTU=  9225
SULFUR= 1.01%, ASH= 10.38%, BTU= 11591
FIXED CARBON= 46.53%, VOLATILE MATTER= 43.09%
DRY MINERAL MATTER FREE FIXED CARBON= 52.56%
DRY MINERAL MATTER FREE VOLATILE MATTER= 47.44%
DRY MINERAL MATTER FREE BTU= 13065
MOIST MINERAL MATTER FREE BTU= 10398
EPA STANDARD-% SULFUR= .70%
RANK=
CLASS III-2, SUBBITUMINOUS B


WELDON-UNTREATED
MOISTURE=13.29%, MOISTBTU= 10197
SULFUR= 6.39%, ASH= 15.74%, BTU= 11760
FIXED CARBON= 43.64%, VOLATILE MATTER= 40.62%
DRY MINERAL MATTER FREE FIXED CARBON= 53.70%
DRY MINERAL MATTER FREE VOLATILE MATTER= 46.30%
DRY MINERAL MATTER FREE BTU= 14331
MOIST MINERAL MATTER FREE BTU= 12427
EPA STANDARD-% SULFUR= .71%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C


EAGLE NO.2-UNTREATED
MOISTURE= 3.31%, MOISTBTU= 10216
SULFUR= 4.29%, ASH= 26.53%, BTU= 10566
FIXED CARBON= 39.17%, VOLATILE MATTER= 34.30%
DRY MINERAL MATTER FREE FIXED CARBON= 55.85%
DRY MINERAL MATTER FREE VOLATILE MATTER= 44.15%
DRY MINERAL MATTER FREE BTU= 14994
MOIST MINERAL MATTER FREE BTU= 14498
EPA STANDARD-% SULFUR= .63%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


ORIENT NO.6-UNTREATED
MOISTURE= 3.51%, MOISTBTU= 10771
SULFUR= 1.66%, ASH= 22.51%, BTU= 11163
FIXED CARBON= 45.82%, VOLATILE MATTER= 31.67%
DRY MINERAL MATTER FREE FIXED CARBON= 60.94%
DRY MINERAL MATTER FREE VOLATILE MATTER= 39.06%
DRY MINERAL MATTER FREE BTU= 14814
MOIST MINERAL MATTER FREE BTU= 14294
EPA STANDARD-% SULFUR= .67%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

Reproduced from best available copy.

```
CAMP NOS.1&2-UNTREATED
MOISTURE= 3.99%, MOISTBTU= 10662
SULFUR= 4.51%, ASH= 21.13%, BTU= 11105
FIXED CARBON= 43.01%, VOLATILE MATTER= 35.86%
DRY MINERAL MATTER FREE FIXED CARBON= 56.67%
DRY MINERAL MATTER FREE VOLATILE MATTER= 43.33%
DRY MINERAL MATTER FREE BTU= 14552
MOIST MINERAL MATTER FREE BTU= 13971
EPA STANDARD-% SULFUR= .67%
RANK=
CLASS II-4, BITUMINOUS-HIGH VOLATILE B


WALKER-UNTREATED
MOISTURE= 2.07%, MOISTBTU= 12341
SULFUR=  .71%, ASH= 16.67%, BTU= 12602
FIXED CARBON= 64.44%, VOLATILE MATTER= 18.89%
DRY MINERAL MATTER FREE FIXED CARBON= 78.83%
DRY MINERAL MATTER FREE VOLATILE MATTER= 21.17%
DRY MINERAL MATTER FREE BTU= 15398
MOIST MINERAL MATTER FREE BTU= 15079
EPA STANDARD-% SULFUR= .76%
RANK=
CLASS II-1, BITUMINOUS-LOW VOLATILE


EGYPT VALLEY NO.21-UNTREATED
MOISTURE= 2.07%, MOISTBTU= 10375
SULFUR= 6.55%, ASH= 25.29%, BTU= 10594
FIXED CARBON= 38.59%, VOLATILE MATTER= 36.12%
DRY MINERAL MATTER FREE FIXED CARBON= 54.44%
DRY MINERAL MATTER FREE VOLATILE MATTER= 45.56%
DRY MINERAL MATTER FREE BTU= 14851
MOIST MINERAL MATTER FREE BTU= 14543
EPA STANDARD-% SULFUR= .64%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


NO.1(DIXIE FUEL)-UNTREATED
MOISTURE= 2.22%, MOISTBTU= 12764
SULFUR= 3.12%, ASH= 11.39%, BTU= 13054
FIXED CARBON= 49.70%, VOLATILE MATTER= 38.91%
DRY MINERAL MATTER FREE FIXED CARBON= 57.26%
DRY MINERAL MATTER FREE VOLATILE MATTER= 42.74%
DRY MINERAL MATTER FREE BTU= 14997
MOIST MINERAL MATTER FREE BTU= 14664
EPA STANDARD-% SULFUR= .78%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

```
JANE-UNTREATED
MOISTURE= 1.17%, MOISTBTU= 11792
SULFUR= 1.85%, ASH= 21.75%, BTU= 11932
FIXED CARBON= 48.18%, VOLATILE MATTER= 30.07%
DRY MINERAL MATTER FREE FIXED CARBON= 63.45%
DRY MINERAL MATTER FREE VOLATILE MATTER= 36.55%
DRY MINERAL MATTER FREE BTU= 15682
MOIST MINERAL MATTER FREE BTU= 15498
EPA STANDARD-% SULFUR= .72%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


FOX-UNTREATED
MOISTURE= 1.83%, MOISTBTU= 12736
SULFUR= 3.83%, ASH= 13.55%, BTU= 12973
FIXED CARBON= 48.12%, VOLATILE MATTER= 38.33%
DRY MINERAL MATTER FREE FIXED CARBON= 57.11%
DRY MINERAL MATTER FREE VOLATILE MATTER= 42.89%
DRY MINERAL MATTER FREE BTU= 15347
MOIST MINERAL MATTER FREE BTU= 15066
EPA STANDARD-% SULFUR= .78%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


WARWICK-UNTREATED
MOISTURE= 1.50%, MOISTBTU=  8483
SULFUR= 1.37%, ASH= 40.47%, BTU=  8612
FIXED CARBON= 31.76%, VOLATILE MATTER= 27.77%
DRY MINERAL MATTER FREE FIXED CARBON= 56.82%
DRY MINERAL MATTER FREE VOLATILE MATTER= 43.18%
DRY MINERAL MATTER FREE BTU= 15381
MOIST MINERAL MATTER FREE BTU= 15150
EPA STANDARD-% SULFUR= .52%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


HUMPHREY NO.7-UNTREATED
MOISTURE= 1.63%, MOISTBTU= 13409
SULFUR= 2.58%, ASH=  9.88%, BTU= 13631
FIXED CARBON= 52.46%, VOLATILE MATTER= 37.66%
DRY MINERAL MATTER FREE FIXED CARBON= 59.23%
DRY MINERAL MATTER FREE VOLATILE MATTER= 40.77%
DRY MINERAL MATTER FREE BTU= 15356
MOIST MINERAL MATTER FREE BTU= 15106
EPA STANDARD-% SULFUR= .82%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

Table B-2

Coal Ranking Data-Pyritic Sulfur Extractions

```
EDNA-TREATED
MOISTURE= 8.41%, MOISTBTU= 11175
SULFUR= 1.14%, ASH=  6.77%, BTU= 12201
FIXED CARBON= 50.88%, VOLATILE MATTER= 42.35%
DRY MINERAL MATTER FREE FIXED CARBON= 55.08%
DRY MINERAL MATTER FREE VOLATILE MATTER= 44.92%
DRY MINERAL MATTER FREE BTU= 13186
MOIST MINERAL MATTER FREE BTU= 12077
EPA STANDARD-% SULFUR= .73%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C



NAVAJO-TREATED
MOISTURE=11.07%, MOISTBTU=  8924
SULFUR=  .76%, ASH= 20.53%, BTU= 10035
FIXED CARBON= 43.65%, VOLATILE MATTER= 35.82%
DRY MINERAL MATTER FREE FIXED CARBON= 56.24%
DRY MINERAL MATTER FREE VOLATILE MATTER= 43.76%
DRY MINERAL MATTER FREE BTU= 12908
MOIST MINERAL MATTER FREE BTU= 11479
EPA STANDARD-% SULFUR= .60%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C,AGGLOMERATING
CLASS III-1,SUBBITUMINOUS A,NONAGGLOMERATING



BELLE AYR-TREATED
MOISTURE=19.14%, MOISTBTU=  9315
SULFUR=  .82%, ASH=  3.37%, BTU= 11520
FIXED CARBON= 49.61%, VOLATILE MATTER= 47.02%
DRY MINERAL MATTER FREE FIXED CARBON= 51.60%
DRY MINERAL MATTER FREE VOLATILE MATTER= 48.40%
DRY MINERAL MATTER FREE BTU= 11958
MOIST MINERAL MATTER FREE BTU=  9670
EPA STANDARD-% SULFUR= .69%
RANK=
CLASS III-2, SUBBITUMINOUS B
```

```
COLSTRIP-TREATED
MOISTURE=20.41%, MOISTBTU=  9010
SULFUR=  .69%, ASH=  5.17%, BTU= 11321
FIXED CARBON= 52.38%, VOLATILE MATTER= 42.45%
DRY MINERAL MATTER FREE FIXED CARBON= 55.59%
DRY MINERAL MATTER FREE VOLATILE MATTER= 44.41%
DRY MINERAL MATTER FREE BTU= 11993
MOIST MINERAL MATTER FREE BTU=  9545
EPA STANDARD-% SULFUR= .68%
RANK=
CLASS III-2, SUBBITUMINOUS B


WELDON-TREATED
MOISTURE=13.29%, MOISTBTU= 10833
SULFUR= 2.34%, ASH=  6.43%, BTU= 12493
FIXED CARBON= 54.96%, VOLATILE MATTER= 38.61%
DRY MINERAL MATTER FREE FIXED CARBON= 59.51%
DRY MINERAL MATTER FREE VOLATILE MATTER= 40.49%
DRY MINERAL MATTER FREE BTU= 13467
MOIST MINERAL MATTER FREE BTU= 11677
EPA STANDARD-% SULFUR= .75%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C


EAGLE NO.2-TREATED
MOISTURE= 3.31%, MOISTBTU= 11024
SULFUR= 2.12%, ASH= 19.80%, BTU= 11401
FIXED CARBON= 45.70%, VOLATILE MATTER= 34.50%
DRY MINERAL MATTER FREE FIXED CARBON= 58.60%
DRY MINERAL MATTER FREE VOLATILE MATTER= 41.40%
DRY MINERAL MATTER FREE BTU= 14579
MOIST MINERAL MATTER FREE BTU= 14096
EPA STANDARD-% SULFUR= .68%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


ORIENT NO.6-TREATED
MOISTURE= 3.51%, MOISTBTU= 10647
SULFUR= 1.40%, ASH= 18.85%, BTU= 11034
FIXED CARBON= 49.23%, VOLATILE MATTER= 31.92%
DRY MINERAL MATTER FREE FIXED CARBON= 62.15%
DRY MINERAL MATTER FREE VOLATILE MATTER= 37.85%
DRY MINERAL MATTER FREE BTU= 13898
MOIST MINERAL MATTER FREE BTU= 13410
EPA STANDARD-% SULFUR= .66%
RANK=
CLASS II-4, BITUMINOUS-HIGH VOLATILE B
```

```
CAMP NOS.1&2-TREATED
MOISTURE= 3.99%, MOISTBTU= 11272
SULFUR= 2.77%, ASH= 15.77%, BTU= 11740
FIXED CARBON= 47.78%, VOLATILE MATTER= 36.45%
DRY MINERAL MATTER FREE FIXED CARBON= 58.16%
DRY MINERAL MATTER FREE VOLATILE MATTER= 41.84%
DRY MINERAL MATTER FREE BTU= 14238
MOIST MINERAL MATTER FREE BTU= 13669
EPA STANDARD-% SULFUR= .70%
RANK=
CLASS II-4, BITUMINOUS-HIGH VOLATILE B


EGYPT VALLEY NO.21-TREATED
MOISTURE= 2.07%, MOISTBTU= 11268
SULFUR= 2.89%, ASH= 18.86%, BTU= 11506
FIXED CARBON= 43.06%, VOLATILE MATTER= 38.08%
DRY MINERAL MATTER FREE FIXED CARBON= 54.62%
DRY MINERAL MATTER FREE VOLATILE MATTER= 45.38%
DRY MINERAL MATTER FREE BTU= 14554
MOIST MINERAL MATTER FREE BTU= 14253
EPA STANDARD-% SULFUR= .69%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


NO.1(DIXIE FUEL)-TREATED
MOISTURE= 2.22%, MOISTBTU= 13045
SULFUR= 1.62%, ASH=  8.50%, BTU= 13341
FIXED CARBON= 53.87%, VOLATILE MATTER= 37.63%
DRY MINERAL MATTER FREE FIXED CARBON= 59.63%
DRY MINERAL MATTER FREE VOLATILE MATTER= 40.37%
DRY MINERAL MATTER FREE BTU= 14743
MOIST MINERAL MATTER FREE BTU= 14416
EPA STANDARD-% SULFUR= .80%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


JANE-TREATED
MOISTURE= 1.17%, MOISTBTU= 12272
SULFUR=  .67%, ASH= 17.99%, BTU= 12417
FIXED CARBON= 51.65%, VOLATILE MATTER= 30.36%
DRY MINERAL MATTER FREE FIXED CARBON= 64.27%
DRY MINERAL MATTER FREE VOLATILE MATTER= 35.73%
DRY MINERAL MATTER FREE BTU= 15440
MOIST MINERAL MATTER FREE BTU= 15259
EPA STANDARD-% SULFUR= .75%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

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```
FOX-TREATED
MOISTURE= 1.83%, MOISTBTU= 12933
SULFUR= 1.64%, ASH=  9.72%, BTU= 13174
FIXED CARBON= 51.97%, VOLATILE MATTER= 38.31%
DRY MINERAL MATTER FREE FIXED CARBON= 58.38%
DRY MINERAL MATTER FREE VOLATILE MATTER= 41.62%
DRY MINERAL MATTER FREE BTU= 14775
MOIST MINERAL MATTER FREE BTU= 14504
EPA STANDARD-% SULFUR= .79%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


WARWICK-TREATED
MOISTURE= 1.50%, MOISTBTU=  9225
SULFUR=  .82%, ASH= 35.32%, BTU=  9365
FIXED CARBON= 38.07%, VOLATILE MATTER= 26.61%
DRY MINERAL MATTER FREE FIXED CARBON= 61.80%
DRY MINERAL MATTER FREE VOLATILE MATTER= 38.20%
DRY MINERAL MATTER FREE BTU= 15184
MOIST MINERAL MATTER FREE BTU= 14956
EPA STANDARD-% SULFUR= .56%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


HUMPHREY NO.7-TREATED
MOISTURE= 1.63%, MOISTBTU= 13722
SULFUR= 1.49%, ASH=  6.97%, BTU= 13949
FIXED CARBON= 55.99%, VOLATILE MATTER= 37.04%
DRY MINERAL MATTER FREE FIXED CARBON= 60.85%
DRY MINERAL MATTER FREE VOLATILE MATTER= 39.15%
DRY MINERAL MATTER FREE BTU= 15137
MOIST MINERAL MATTER FREE BTU= 14890
EPA STANDARD-% SULFUR= .84%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

Table B-3

Coal Ranking Data-Organic Sulfur Extractions

```
EAGLE NO.2-TREATED
MOISTURE= 3.31%, MOISTBTU=  9464
SULFUR= 4.16%, ASH= 30.58%, BTU=  9788
FIXED CARBON= 39.62%, VOLATILE MATTER= 29.80%
DRY MINERAL MATTER FREE FIXED CARBON= 60.29%
DRY MINERAL MATTER FREE VOLATILE MATTER= 39.71%
DRY MINERAL MATTER FREE BTU= 14799
MOIST MINERAL MATTER FREE BTU= 14309
EPA STANDARD-% SULFUR= .59%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

```
CAMP NOS.1&2-TREATED
MOISTURE= 3.99%, MOISTBTU= 10078
SULFUR= 5.18%, ASH= 25.66%, BTU= 10497
FIXED CARBON= 41.11%, VOLATILE MATTER= 33.23%
DRY MINERAL MATTER FREE FIXED CARBON= 58.08%
DRY MINERAL MATTER FREE VOLATILE MATTER= 41.92%
DRY MINERAL MATTER FREE BTU= 14729
MOIST MINERAL MATTER FREE BTU= 14141
EPA STANDARD-% SULFUR= .63%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

```
ORIENT NO.6-TREATED
MOISTURE= 3.51%, MOISTBTU= 10287
SULFUR= 1.83%, ASH= 24.55%, BTU= 10661
FIXED CARBON= 45.25%, VOLATILE MATTER= 30.20%
DRY MINERAL MATTER FREE FIXED CARBON= 62.05%
DRY MINERAL MATTER FREE VOLATILE MATTER= 37.95%
DRY MINERAL MATTER FREE BTU= 14578
MOIST MINERAL MATTER FREE BTU= 14066
EPA STANDARD-% SULFUR= .64%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

```
BELLE AYR-TREATED
MOISTURE=19.14%, MOISTBTU=  9667
SULFUR=  .79%, ASH=  7.78%, BTU= 11955
FIXED CARBON= 45.48%, VOLATILE MATTER= 46.74%
DRY MINERAL MATTER FREE FIXED CARBON= 49.76%
DRY MINERAL MATTER FREE VOLATILE MATTER= 50.24%
DRY MINERAL MATTER FREE BTU= 13060
MOIST MINERAL MATTER FREE BTU= 10561
EPA STANDARD-% SULFUR= .72%
RANK=
CLASS II-5, BITUMINOUS-HIGH VOLATILE C,AGGLOMERATING
CLASS III-1,SUBBITUMINOUS A,NONAGGLOMERATING


FOX-TREATED
MOISTURE= 1.83%, MOISTBTU= 12025
SULFUR= 4.13%, ASH= 16.49%, BTU= 12249
FIXED CARBON= 48.62%, VOLATILE MATTER= 34.89%
DRY MINERAL MATTER FREE FIXED CARBON= 60.06%
DRY MINERAL MATTER FREE VOLATILE MATTER= 39.94%
DRY MINERAL MATTER FREE BTU= 15064
MOIST MINERAL MATTER FREE BTU= 14788
EPA STANDARD-% SULFUR= .73%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A


COLSTRIP-TREATED
MOISTURE=20.41%, MOISTBTU=  9053
SULFUR=  .90%, ASH= 10.28%, BTU= 11374
FIXED CARBON= 49.09%, VOLATILE MATTER= 40.63%
DRY MINERAL MATTER FREE FIXED CARBON= 55.38%
DRY MINERAL MATTER FREE VOLATILE MATTER= 44.62%
DRY MINERAL MATTER FREE BTU= 12802
MOIST MINERAL MATTER FREE BTU= 10189
EPA STANDARD-% SULFUR= .68%
RANK=
CLASS III-2, SUBBITUMINOUS B


JANE-TREATED
MOISTURE= 1.17%, MOISTBTU= 10980
SULFUR= 2.08%, ASH= 25.48%, BTU= 11110
FIXED CARBON= 46.81%, VOLATILE MATTER= 27.71%
DRY MINERAL MATTER FREE FIXED CARBON= 65.18%
DRY MINERAL MATTER FREE VOLATILE MATTER= 34.82%
DRY MINERAL MATTER FREE BTU= 15426
MOIST MINERAL MATTER FREE BTU= 15246
EPA STANDARD-% SULFUR= .67%
RANK=
CLASS II-3, BITUMINOUS-HIGH VOLATILE A
```

Table B-4

Computer Program for Determining the Rank of Coal

```
      PROGRAM RANK (INPUT,OUTPUT,TAPE6)
C     CLASSIFICATION OF COALS BY RANK
      REWIND 6
      PRINT 67
   67 FORMAT (◆PRINTOUT IS SAVED ON TAPE 6◆)
    1 PRINT 9
    9 FORMAT (◆INPUT COAL NAME OR NUMBER◆)
      READ 8,Q,O,P,M
    8 FORMAT (A8,A8,A8,A8)
      PRINT 2
    2 FORMAT (◆INPUT SULFUR, ASH, BTU, VOLATILE MATTER, AND MOISTURE◆)
      ACCEPT SULFUR,ASH,BTUD,VM,AMOIST
      FC=100-(ASH+VM)
      BTU=BTUD◆((100.-AMOIST)/100.)
      DRYFC=((FC-0.15◆SULFUR)/(100.-(1.08◆ASH+0.55◆SULFUR)))◆100.
      DRYVM=100.-DRYFC
      WETBTU=((BTU-50◆SULFUR)/(100.-(1.08◆ASH+0.55◆SULFUR)))◆100.
      DRYBTU=WETBTU/((100.-AMOIST)/100.)
C     WTCOL=POUNDS COAL PER 1.0E+06 DRY BASIS BTU
      WTCOL=1.0E+06/BTUD
C     WTSUL=POUNDS SULFUR PER 1.0E+06 DRY BASIS BTU
      WTSUL=WTCOL◆SULFUR/100.
C     EPASUL=PERCENT SULFUR TO MEET EPA STANDARD OF 0.6
C     POUNDS SULFUR PER 1.0E+06 BTU
      EPASUL=SULFUR◆0.60/WTSUL
      PRINT 700
      PRINT 8,Q,O,P,M
      PRINT 6, AMOIST,BTU
      PRINT 3, SULFUR, ASH, BTUD, FC, VM
      WRITE (6,700)
      WRITE (6,8) Q,O,P,M
      WRITE (6,6) AMOIST,BTU
      WRITE (6,3) SULFUR,ASH,BTUD,FC,VM
      WRITE (6,4) DRYFC,DRYVM,DRYBTU,WETBTU
      WRITE (6,7) EPASUL
      WRITE (6,5)
    6 FORMAT (◆MOISTURE=◆,F5.2,◆%, MOISTBTU=◆,F6.0)
    3 FORMAT (◆SULFUR=◆,F5.2,◆%, ASH=◆,F6.2,◆%, BTU=◆,F6.0,/◆FIXED◆
     1◆ CARBON=◆,F6.2,◆%, VOLATILE MATTER=◆,F6.2,◆%◆)
      PRINT 4, DRYFC,DRYVM,DRYBTU,WETBTU
    4 FORMAT (◆DRY MINERAL MATTER FREE FIXED CARBON=◆,F6.2,◆%◆/
     1◆DRY MINERAL MATTER FREE VOLATILE MATTER=◆,F6.2,◆%◆/
     2◆DRY MINERAL MATTER FREE BTU=◆,F6.0/
     3◆MOIST MINERAL MATTER FREE BTU=◆,F6.0)
```

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```
      PRINT 7, EPASUL
    7 FORMAT (*EPA STANDARD-% SULFUR=*,F4.2,*%*)
      PRINT 5
    5 FORMAT (*RANK=*)
C     RANK SORTING
      IF (DRYFC-98.) 11,10,10
   11 IF (DRYFC-92.) 12,20,20
   12 IF (DRYFC-86.) 13,30,30
   13 IF (DRYFC-78.) 14,40,40
   14 IF (DRYFC-69.) 15,50,50
   15 IF (WETBTU-14000.) 16,60,60
   16 IF (WETBTU-13000.) 17,70,70
   17 IF (WETBTU-11500.) 18,80,80
   18 IF (WETBTU-10500.) 19,90,90
   19 IF (WETBTU-9500.) 200,100,100
  200 IF (WETBTU-8300.) 22,110,110
   22 IF (WETBTU-6300.) 23,120,120
   23 IF(WETBTU-6300.) 130,10,10
   10 PRINT 1111
      WRITE (6,1111)
      GO TO 1000
   20 PRINT 21
      WRITE (6,21)
      GO TO 1000
   30 PRINT 31
      WRITE (6,31)
      GO TO 1000
   40 PRINT 41
      WRITE (6,41)
      GO TO 1000
   50 PRINT 51
      WRITE (6,51)
      GO TO 1000
   60 PRINT 61
      WRITE (6,61)
      GO TO 1000
   70 PRINT 71
      WRITE (6,71)
      GO TO 1000
   80 PRINT 81
      WRITE (6,81)
      GO TO 1000
   90 PRINT 91
      WRITE (6,91)
      GO TO 1000
  100 PRINT 101
      WRITE (6,101)
      GO TO 1000
```

```
 110 PRINT 111
     WRITE (6,111)
     GO TO 1000
 120 PRINT 121
     WRITE (6,121)
      GO TO 1000
 130 PRINT 131
     WRITE (6,131)
1111 FORMAT (◆CLASS I-1, META-ANTHRACITE◆)
  21 FORMAT (◆CLASS I-2, ANTHRACITE◆)
  31 FORMAT (◆CLASS I-3, SEMIANTHRACITE◆)
  41 FORMAT (◆CLASS II-1, BITUMINOUS-LOW VOLATILE◆)
  51 FORMAT (◆CLASS II-2, BITUMINOUS-MEDIUM VOLATILE◆)
  61 FORMAT (◆CLASS II-3, BITUMINOUS-HIGH VOLATILE A◆)
  71 FORMAT (◆CLASS II-4, BITUMINOUS-HIGH VOLATILE B◆)
  81 FORMAT (◆CLASS II-5, BITUMINOUS-HIGH VOLATILE C◆)
  91 FORMAT (◆CLASS II-5, BITUMINOUS-HIGH VOLATILE C,◆
    1◆AGGLOMERATING◆/◆CLASS III-1,SUBBITUMINOUS A,NONAGGLOMERATING◆)
 101 FORMAT (◆CLASS III-2, SUBBITUMINOUS B◆)
 111 FORMAT (◆CLASS III-3, SUBBITUMINOUS C◆)
 121 FORMAT (◆CLASS IV-1, LIGNITE A◆)
 131 FORMAT (◆CLASS IV-2, LIGNITE B◆)
1000 PRINT 700
 700 FORMAT (//)
     PRINT 68
  68 FORMAT (◆GO?=1◆)
     ACCEPT GO
     IF (GO) 69,69,1
  69 PRINT 700
     END
```

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Appendix C

Untreated Coal Analyses Data

TABLE C-1

UNTREATED COAL ANALYSES

EDNA, NAVAJO, BELLE AYR, AND COLSTRIP MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Edna Mine, Wadge Seam, Routt County, Colorado	A	8.27	0.78	0.14	0.00	0.64	9.12	41.13	49.75	12212
	B	8.54	0.75	0.16	0.00	0.59	9.12	39.80	51.08	12277
	C	8.42	0.71	0.13	0.00	0.61	9.16	41.02	49.82	12250
	Average	8.41	0.75	0.14	0.00	0.61	9.13	40.65	50.22	12246
	Std. Dev.	±.135	±.035	±.015	±.00	±.038	± .023	± .738	± .748	±32.7
Navajo Mine, Nos.6, 7, & 8 Seams San Juan County, New Mexico	A	11.07	0.80	0.30	0.03	0.47	25.13	35.53	39.34	9934
	B	11.04	0.81	0.23	0.03	0.55	25.12	36.65	38.23	10170
	C	11.11	0.81	0.31	0.03	0.47	25.61	34.35	40.64	10047
	Average	11.07	0.81	0.28	0.03	0.50	25.29	35.51	39.20	10050
	Std. Dev.	± .035	±.006	±.044	±.00	±.044	± .280	±1.15	±1.21	±118
Belle Ayr Mine, Roland-Smith Seam, Campbell County, Wyoming	A	19.15	0.74	0.20	0.00	0.54	7.59	47.19	45.22	12088
	B	18.94	0.79	0.23	0.00	0.56	7.48	48.61	43.91	11949
	C	19.34	0.74	0.23	0.00	0.51	7.57	45.52	46.91	12065
	Average	19.14	0.76	0.22	0.00	0.54	7.55	47.11	45.34	12034
	Std. Dev.	± .200	±.029	±.017	±.00	±.035	±.058	±1.55	±1.50	±74.5
Colstrip Mine, Rosebud Seam, Rosebud County, Montana	A	20.64	1.01	0.34	0.00	0.67	10.46	43.64	45.90	11529
	B	20.21	1.02	0.33	0.00	0.69	10.31	42.26	47.43	11581
	C	20.38	1.01	0.36	0.00	0.65	10.37	43.38	46.25	11662
	Average	20.41	1.01	0.34	0.00	0.67	10.38	43.09	46.53	11591
	Std. Dev.	± .216	±.006	±.015	±.00	±.019	± .075	± .733	± .801	±67.0

TABLE C-2

UNTREATED COAL ANALYSES

WELDON, EAGLE NO.2, ORIENT NO.6 AND CAMP NOS. 1 & 2 MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Weldon Mine, Des Moines No. 1 Seam, Marion County, Iowa	A	13.19	6.35	5.28	0.15	0.92	15.68	40.43	43.89	11750
	B	13.13	6.42	5.22	0.16	1.04	15.64	41.00	43.56	11779
	C	13.55	6.40	5.21	0.15	1.04	15.89	40.42	43.68	11750
	Average	13.29	6.39	5.24	0.15	1.00	15.74	40.62	43.64	11760
	Std. Dev.	± .227	±.036	±.038	±.006	±.052	± .134	± .332	± .167	±16.7
Eagle No. 2 Mine, Illinois No. 5 Seam, Gallatin County, Illinois	A	3.28	4.27 4.27	2.51 2.49	0.02 0.03	1.74 1.75	26.76	33.62	39.62	10479
	B	3.24	4.27 4.32	2.70 2.53	0.06 0.04	1.54 1.75	26.45	34.48	39.07	10573
	C	3.42	4.31 4.28	2.74 2.87	0.06 0.06	1.51 1.35	26.38	34.80	38.82	10377
	Average	3.31	4.29	2.64	0.04	1.61	26.53	34.30	39.17	10566
	Std. Dev.	±.095	±.023	±.154	±.017	±.156	± .202	± .610	± .409	±186
Orient No. 6 Mine, Herrin No. 6 Seam, Jefferson County, Illinois	A	3.41	1.64 1.63	1.21	0.02	0.42	22.59	31.49	45.92	11164
	B	3.65	1.55 1.66	1.29	0.00	0.37	22.39	31.53	46.08	11165
	C	3.47	1.69 1.76	1.27 1.41	0.00 0.00	0.42 0.35	22.54	32.04	45.42	11159
	Average	3.51	1.66	1.30	0.00	0.36	22.51	31.67	45.82	11163
	Std. Dev.	± .119	±.069	±.084	±.010	±.109	± .104	± .307	± .344	±3.21
Camp Nos. 1 & 2 Mine, No. 9 Seam, Union County, (West) Kentucky	A	4.32	4.49 4.47	2.64 2.86	0.06	1.79 1.55	20.90	35.42	43.68	11213
	B	3.29	4.53 4.58	2.75 2.84	0.06	1.72 1.68	21.05	36.63	42.32	11088
	C	4.37	4.57 4.47	2.98 2.73	0.06	1.53 1.68	21.44	35.52	43.04	11013
	Average	3.99	4.51	2.80	0.06	1.65	21.13	35.86	43.01	11105
	Std. Dev.	± .615	±.049	±.120	±.00	±.130	± .387	± .672	± .680	±101

TABLE C-3

UNTREATED COAL ANALYSES

WALKER, EGYPT VALLEY NO. 21, NO. 1[a] AND JANE MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Walker Mine, Upper Kittanning Seam, Garrett County, Maryland	A	2.08	0.70 0.72	0.11	0.00	0.60	16.65	18.56	64.79	12617
	B	2.02	0.64 0.71	0.00	0.00	0.70	16.68	18.96	64.36	12586
	C	2.11	0.74 0.72	0.09	0.00	0.64	16.67	19.15	64.18	12605
	Average	2.07	0.71	0.07	0.00	0.64	16.67	18.89	64.44	12602
	Std. Dev.	± .045	±.018	±.059	±.00	±.062	± .015	± .301	± .313	±15.6
Egypt Valley No. 21 Mine, Pittsburgh No. 8 Seam, Belmont County, Ohio	A	1.72	6.55	5.07	0.14	1.34	25.26	36.35	38.39	10570
	B	2.02	6.56	5.05	0.14	1.37	25.43	35.80	38.77	10563
	C	2.48	6.55	5.10	0.14	1.31	25.17	36.27	38.56	10648
	Average	2.07	6.55	5.07	0.14	1.34	25.29	36.12	38.59	10594
	Std. Dev.	± .383	±.006	±.025	±.00	±.026	± .132	± .286	± .190	±47.2
No. 1 Mine,[a] Mason Seam, Harlan County, (East) Kentucky	A	2.21	3.16	2.00	0.08	1.08	11.45	38.50	50.05	13102
	B	2.24	3.00	1.91	0.08	1.01	11.41	39.13	49.46	13018
	C	2.21	3.21	2.03	0.08	1.10	11.31	39.10	49.59	13043
	Average	2.22	3.12	1.98	0.08	1.06	11.39	38.91	49.70	13054
	Std. Dev.	± .017	±.110	±.062	±.00	±.126	± .072	± .355	± .310	±43.1
Jane Mine Lower Freeport Seam, Armstrong County, Pennsylvania	A	1.16	1.87 1.85	1.36 1.45	0.00	0.51 0.40	21.84	29.91	48.25	11936
	B	1.22	1.85 1.87	1.48 1.47	0.00 0.04	0.37 0.39	21.69	30.40	47.91	11968
	C	1.33	1.85 1.83	1.45	0.00	0.38	21.71	29.89	48.40	11892
	Average	1.17	1.85	1.44	0.002	0.41	21.75	30.07	48.18	11932
	Std. Dev.	± .045	±.015	±.048	±.004	±.051	± .081	± .289	± .250	±38.2

[a] Dixie Fuel Company

TABLE C-4
UNTREATED COAL ANALYSES
FOX, WARWICK AND HUMPHREY NO. 7 MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Fox Mine, Lower Kittanning Seam, Clarion County, Pennsylvania	A	1.80	3.86 3.80	3.10	0.05	0.67	13.56	37.76	48.68	12960
	B	1.60	3.79 3.83	3.07	0.03	0.71	13.52	38.92	47.56	12966
	C	2.07	3.81 3.83	3.10	0.06	0.66	13.58	38.32	48.12	12933
	Average	1.83	3.83	3.09	0.05	0.69	13.55	38.33	48.12	12973
	Std. Dev.	±.236	±.038	±.017	±.015	±.044	± .031	± .580	± .560	±17.6
Warwick Mine, Sewickley Seam, Greene County, Pennsylvania	A	1.65	1.37	1.18	0.01	0.18	40.72	23.13	31.15	8657
	B	1.38	1.35	1.07	0.01	0.27	40.48	27.04	32.48	8606
	C	1.47	1.39	1.01	0.00	0.38	40.22	28.14	31.64	8574
	Average	1.50	1.37	1.09	0.01	0.27	40.47	27.77	31.76	8612
	Std. Dev.	±.137	±.020	±.086	±.006	±.088	± .250	± .632	± .673	±41.9
Humphrey No. 7 Mine, Pittsburgh Seam, Monongalia County, West Virginia	A	1.51	2.54	1.56	0.00	0.98	9.85	37.68	52.47	13554
	B	1.71	2.59	1.50	0.01	1.08	9.89	37.91	52.20	13601
	C	1.67	2.61	1.70	0.02	0.87	9.89	37.39	52.72	13740
	Average	1.63	2.58	1.59	0.01	0.98	9.88	37.66	52.46	13631
	Std. Dev.	±.105	±.036	±.114	±.010	±.120	± .023	± .260	± .260	±96.7

Appendix D

Pyritic Sulfur Removal Data

Notes: The complete general procedure used to treat the coals is contained in Section 4.3 of this report. Variables such as mesh, reaction time, and leach numbers and times are listed in the tables. Numbers in parenthesis are not considered valid for various reasons and are included for completeness. Averages are included only where appropriate.

TABLE D-1

PYRITIC SULFUR REMOVAL DATA

EDNA, NAVAJO, BELLE AYR AND COLSTRIP MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Btu/lb
Edna Mine,	100	23	1	5.0	1	1.15	0.04	0.50	0.61	6.72	43.06	50.22	12185
Wadge Seam,	100	23	1	5.0	2	1.16	0.09	0.49	0.58	6.73	42.57	50.70	12247
Routt County,	100	23	1	5.0	3	1.11	0.05	0.48	0.58	6.86	41.41	51.73	12172
Colorado			Treated Average Std. Dev.		1-3	1.14 ±.026	0.06 ±.020	0.49 ±.010	0.59 ±.043	6.77 ±.078	±42.35 ±.847	50.88 ±.772	12201 ±40.1
			Initial Average Std. Dev.		A-C	0.75 ±.035	0.14 ±.0153	0.00 ±.01	0.61 ±.038	9.13 ±.003	40.65 ±.738	50.22 ±.748	12246 ±32.7
Navajo Mine,	100	23	2	5.0.13.5	1	0.83	0.00	0.15	.68	20.73	36.36	42.98	9996
Nos.6,7,8 Seams	100	23	2	5.0.13.5	2	0.75	0.08	0.15	.52	20.52	34.99	44.49	10031
San Juan County,	100	23	2	5.0.13.5	3	0.70	0.04	0.14	.52	20.49	36.11	43.40	10080
New Mexico			Treated Average Std. Dev.		1-3	0.76 ±.066	0.04 ±.040	0.15 ±.006	0.57 ±.077	20.53 ±.131	35.82 ±.730	43.60 ±.773	10035 ±42.1
			Initial Average Std. Dev.		A-C	0.81 ±.065	0.28 ±.044	0.03 ±.01	0.50 ±.044	25.29 ±.280	35.51 ±1.15	39.40 ±1.21	10050 ±118
Belle Ayr Mine,	100	6.5	1	4.0	1	0.83	0.02	0.14	0.67	3.32	47.12	49.56	11522
Roland-Smith Seam,	100	10.5	1	6.0	2	0.79	0.04	0.15	0.60	3.29	46.63	50.08	11382
Campbell County,	100	10.5	1	6.0	3	0.84	0.02	0.13	0.69	3.50	47.30	49.20	11655
Wyoming			Treated Average Std. Dev.		1-3	0.82 ±.026	0.03 ±.012	0.14 ±.010	0.65 ±.030	3.37 ±.114	47.02 ±.346	49.61 ±.364	11520 ±136
			Initial Average Std. Dev.		A-C	0.76 ±.029	0.22 ±.0173	0.00 ±.010	0.54 ±.035	7.55 ±.058	47.11 ±1.55	45.34 ±1.50	12034 ±74.5
Colstrip Mine,	100	13	1	4.0	1	0.63	0.06	0.05	0.52	5.04	42.62	52.34	11239
Rosebud Seam,	100	12	2	4.0.7.5	2	0.73	0.06	0.07	0.60	5.14	42.27	52.59	11327
Rosebud County,	100	12	2	4.0.7.5	3	0.72	0.07	0.06	0.59	5.33	42.49	52.18	11398
Montana			Treated Average Std. Dev.		1-3	0.69 ±.055	0.06 ±.006	0.06 ±.010	0.57 ±.056	5.17 ±.148	42.45 ±.177	52.38 ±.231	11321 ±79.7
			Initial Average Std. Dev.		A-C	1.01 ±.066	0.34 ±.015	0.00 ±.010	0.67 ±.019	10.38 ±.075	43.09 ±.733	46.53 ±.801	11591 ±67

TABLE D-2

PYRITIC SULFUR REMOVAL DATA

WELDON, EAGLE NO.2, ORIENT NO.6 AND CAMP NOS. 1 & 2 MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Btu/lb
Weldon Mine,	100	23	2	1.5.8.0	1	2.27	0.40	0.18	1.69	6.46	39.54	54.00	12500
Des Moines No.1 Seam	100	23	2	1.5.8.0	2	2.27	0.42	0.18	1.67	6.35	39.18	54.47	12440
Marion County,	100	23	2	1.5.8.0	3	2.49	0.58	0.18	1.73	6.48	37.10	56.42	12538
Iowa			Treated Average Std. Dev.		1-3	2.34 ±.127	0.47 ±.099	0.18 ±.00	1.69 ±.161	6.43 ±.070	38.61 ±1.32	54.96 ±1.32	12493 ±49.4
	200	13	1		4	2.25	0.15	0.12	1.98	5.94			12735
			Initial Average Std. Dev.		A-C	6.39 ±.036	5.24 ±.038	0.15 ±.006	1.00 ±.069	15.74 ±.134	40.62 ±.332	43.64 ±.167	11760 ±167
Eagle No. 2 Mine	100	13	2	4,7	1	2.14	0.36	0.17	1.61	19.93	35.00	45.07	11428
Illinois No. 5 Seam	100	14	1	8	2	1.97	0.11	0.18	1.68	19.49	34.62	45.89	11507
Gallatin County,	100	14	1	8	3	2.25	0.33	0.18	1.74	19.99	33.87	46.14	11267
Illinois	100	23	1	6	4	2.04	0.19	0.23	1.62				
			Initial Average Std. Dev.		A-C	4.29 ±0.23	2.64 ±.154	0.04 ±.017	1.61 ±.156	26.53 ±.202	34.30 ±.610	39.17 ±.409	10566 ±186
Orient No.6 Mine,	100	23	1	4	1	1.44	0.34	0.60	0.50	19.03	32.18	48.79	10991
Herrin No. 6 Seam	100	23	1	4	2	1.39	0.24	0.67	0.48	18.81	32.05	49.14	11016
Jefferson County,	100	23	1	4	3	1.38	0.39	0.58	0.41	18.72	31.53	49.75	11095
Illinois			Treated Average Std. Dev.		1-3	1.40 ±.032	0.32 ±.076	0.62 ±.047	0.46 ±.095	18.85 ±.159	31.92 ±.344	49.23 ±.486	11034 ±54
	200	23	1		4	1.16	0.12	0.35	0.69				
	200	13	1		5	0.93	0.06	0.17	0.73				
			Initial Average Std. Dev.		A-C	1.66 ±.069	1.30 ±.084	0.00 ±.010	0.36 ±.109	22.51 ±.104	31.67 ±.307	45.82 ±.344	11163 ± 3.2
Camp Nos.1 & 2 Mines	100	13	1	4	1	2.89 2.92	0.83	0.42	1.64 1.67	15.94	36.24	47.82	11640
No. 9 Seam	100	13	1	4	2	2.74 2.78	0.60	0.42	1.72 1.72	15.86	36.30	47.84	11770
Union County,	100	13	1	4	3	2.62 2.64	0.38 0.47	0.39 0.42	1.85 1.75	15.52	36.80	47.68	11809
(West)Kentucky			Treated Average Std. Dev.		1-3	2.77 ±.124	0.62 ±.21	0.42 ±.006	1.73 ±.066	15.77 ±.223	36.45 ±.307	47.78 ±.087	11740 ±88
	100	23	1	3.5	4	2.50	0.33	0.28	1.89				
	200	23	2	2.5,12.5	5	2.35	0.02	0.25	2.08				
	200	13	1	3.5	6	2.02	0.14	0.16	1.72				
			Initial Average Std. Dev.		A-C	4.51 ±.049	2.80 ±.120	0.06 ±.010	1.65 ±.130	21.13 ±.387	35.86 ±.672	43.01 ±.680	11103 ±101

TABLE D-3

PYRITIC SULFUR REMOVAL DATA

EGYPT VALLEY NO.21, NO.1[a], JANE AND FOX MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Btu/lb
Egypt Valley No.21,	100	13	1	6	1	2.91	0.58 0.42	0.10	2.23 2.31	19.21	37.84	42.95	11556
Pittsburgh No.8 Seam Belmont County,	100	22	1	6	2	2.85	0.71 0.52	0.72	2.02 2.27	18.55	39.08	42.37	11532
Ohio	100	22	1	6	3	2.91	0.88	0.12	1.91	18.82	37.31	43.87	11430
			Treated Average Std.Dev.		1-3	2.89 ±.035	0.62 ±.178	0.11 ±.012	2.16 ±.182	18.86 ±.332	38.08 ±.908	43.06 ±.967	11506 ±66
	200	13	1	2	4	2.71	0.38	0.13	2.20	18.69			11533
			Initial Average Std. Dev.		A-C	6.55 ±.006	5.07 ±.025	0.14 ± 00	1.34 ±.026	25.29 ±.132	36.12 ±.286	38.59 ±.190	10594 ±47.2
No. 1 Mine[a]	100	23	1	6	1	1.76	0.17	.11	1.48	8.63	37.76	53.61	13354
Mason Seam,	100	23	1	6	2	1.54	0.21	0.07	1.26	8.37	37.50	54.13	13328
Harlan County	100	23	1	6	3	1.55	.26	.09	1.19	(9.34)	(29.85)	(60.85)	(11518)
(East) Kentucky			Treated Average Std. Dev.		1-3	1.62 ±.124	0.21 ±.045	.09 ±.020	1.32 ±.133	8.50 ±.184	37.63 ±.184	53.87 ±.260	13341 ±18.4
			Initial Average Std. Dev.		A-C	3.12 ±.110	1.98 ±.062	0.08 ± .00	1.06 ±.126	11.39 ±.072	38.91 ±.355	49.90 ±.310	13054 ±43.1
Jane Mine	100	11.5	1	5	1	0.71	0.14	0.06	0.51	18.17	30.44	51.39	12417
Lower Freeport Seam,	100	23	1	11	2	0.66	0.13	0.06	0.47	17.80	30.28	51.92	12417
Armstrong County, Pennsylvania			Treated Average Std. Dev.		1-2	0.69 ±.035	0.14 ±.007	0.06 ± .00	0.49 ±.035	17.99 ±.262	30.36 ±.113	51.65 ±.375	12417 ±0
	100	23	1	11	3	1.08	0.63	0.05	0.40	18.56	30.59	50.85	12341
			Initial Average Std. Dev.		A-C	1.85 ±.015	1.44 ±.098	0.002 ±.004	0.41 ±.051	21.75 ±.081	30.07 ±.288	48.18 ±.250	11932 ±38.2
Fox Mine,	100	23	1	6	1	1.61	0.26	0.10	1.25	9.66	38.62	51.72	~~13126~~
Lower Kittanning Seam,	100	23	1	6	2	1.53	0.20 0.43	0.07 0.11	1.26 0.99	9.72	37.69	52.59	13168
Clarion County, Pennsylvania	100	23	1	6	3	1.77	0.33 0.63	0.04 0.12	1.40 1.02	9.79	38.62	51.59	- 13245
			Treated Average Std. Dev.		1-3	1.64 ±.122	0.37 ±.163	0.09 ±.033	1.18 ±.206	9.72 ±.065	38.31 ±.537	51.97 ±.541	13174 ±60.4
	200	13	1	3	4	1.55	0.47	0.09	0.99	9.71			13325
			Initial Average Std. Dev.		A-C	3.83 ±.038	3.09 ±.017	0.05 ±.015	0.69 ±.044	13.55 ±.031	38.33 ±.580	48.12 ±.560	12973 ±17.6

[a] Dixie Fuel Company.

TABLE D-4

PYRITIC SULFUR REMOVAL DATA

WARWICK AND HUMPHREY NO. 7 MINES AND LOWER KITTANNING COAL

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Btu/lb
Warwick Mine, Sewickley Sean, Green County, Pennsylvania	100	23	1	6	1	0.77	0.04 0.06	0.13 0.15	0.60 0.56	35.46	27.53	37.01	9342
	100	23	1	6	2	0.83	0.05 0.12	0.14 0.15	0.64 0.56	35.14	26.59	38.27	9327
	100	23	1	6	3	0.85	0.12 0.14	0.12 0.14	0.61 0.57	35.36	25.70	38.94	9427
			Treated Average Std. Dev.		1-3	0.82 ±.042	0.09 ±.043	0.14 ±.012	0.59 ±.061	35.32 ±.164	26.61 ±.915	38.07 ±.930	9365 ±5.4
	100	13	0	13	4	0.66	0.06	0.07	0.53				
			Initial Average		A-C	1.37 ±.020	1.09 ±.086	0.007 ±0.006	0.27 ±.088	40.47 ±.250	27.77 ±.632	31.76 ±.673	8612 ±41.9
Humphrey No. 7 Mine Pittsburgh Seam, Monongalia County, Pennsylvania	100	23	1	6	1	1.53	.09	.09	1.35	6.95	36.12	56.93	13851
	100	23	1	6	2	1.53	0.14	0.10	1.29	7.00	36.84	56.16	14064
	100	23	1	6	3	1.41	0.20	0.10	1.11	6.97	38.15	54.88	13931
			Treated Average Std. Dev.		1-3	1.49 ±.069	0.14 ±.055	0.10 ±.006	1.25 ±.088	6.97 ±.025	37.04 ±1.03	55.93 ±1.03	13949 ±10.8
			Initial Average Std. Dev.		A-C	2.58 ±.036	1.59 ±.114	0.01 ±.010	0.98 ±.120	9.89 ±.023	37.66 ±.260	52.46 ±.260	13631 ±96.7
Lower Kittanning Greene County, Pennsylvania	100	12	1	4	1	1.36	0.45	0.30	0.61	13.20			13299
	100	12	1	4	2	1.32	0.41	0.28	0.63	13.91			13114
	100	12	1	4	3	1.35	0.28	.32	0.75	14.42			13213
			Treated Average Std. Dev.		1-3	1.34 ±.021	0.38 ±.089	.30 ±.020	0.60 ±.094	13.84 ±.610			13209 ±92.6
			Initial Average Std. Dev.		A-C	4.29 ±.061	3.58 ±.080	0.04 ±.010	0.67 ±.010	18.77 ±.123			12140 ± 80

Appendix E

Washability Tables

NOTE: Coal washability results have been performed through standard float and sink testing, discussed in Section 4.4.

TABLE E-1.

Peabody Coal Company
Eagle Mine No. 2-No. 5 Seam
Gallatin County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
Sink	Float	%Wt.	%Ash	% Sul. Total	% Sul. Pyr.	%Wt.	%Ash	% Sul. Total	% Sul. Pyr.	%Wt.	%Ash	% Sul. Total	% Sul. Pyr.
	1.30	31.9	4.64	2.29	0.41	31.9	4.64	2.29	0.41	100.0	25.07	4.06	2.74
1.30	1.40	36.6	10.73	2.70	1.21	68.5	7.89	2.51	0.84	68.1	34.64	4.89	3.83
1.40	1.60	8.7	25.60	5.31	4.21	77.2	9.89	2.82	1.22	31.5	62.43	7.44	6.88
1.60	1.90	2.5	34.92	10.76	10.14	79.7	10.67	3.07	1.50	22.8	76.48	8.25	7.90
1.90		20.3	81.60	7.94	7.62	100.0	25.07	4.06	2.74	20.3	81.60	7.94	7.62

Head Sample: 1-1/2" X 100 Mesh = 99.6% of Raw Run of Mine Coal Crushed to 1-1/2"

25.57 4.04 2.70

100 Mesh X 0 = 0.4% of Raw Run of Mine Coal Crushed to 1-1/2"

30.23 4.46 2.95

TABLE E-2.

Peabody Coal Company
Eagle Mine No. 2-No. 5 Seam
Gallatin County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	25.3	3.77	2.25	0.33	25.3	3.77	2.25	0.33	100.0	24.94	4.29	2.86
1.30	1.40	37.4	10.41	2.84	1.18	62.7	7.73	2.60	0.84	74.7	32.11	4.97	3.72
1.40	1.60	15.4	24.39	4.70	3.35	78.1	11.02	3.02	1.33	37.3	53.86	7.11	6.27
1.60	1.90	3.5	34.77	6.25	5.38	81.6	12.03	3.15	1.51	21.9	74.59	8.81	8.32
1.90		18.4	82.16	9.30	8.88	100.0	24.94	4.29	2.86	18.4	82.16	9.30	8.88

Head Sample: 3/8" X 100 Mesh = 97.0% of Raw Run of Mine Coal Crushed to 3/8"

25.43 4.16 2.79

100 Mesh X 0 = 3.0% of Raw Run of Mine Coal Crushed to 3/8"

27.29 4.56 3.27

TABLE E-3.

Peabody Coal Company
Eagle Mine No. 2-No. 5 Seam
Gallatin County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	21.5	3.25	2.27	0.26	21.5	3.25	2.27	0.26	100.0	25.07	3.94	2.77
1.30	1.40	38.4	9.22	2.64	1.38	59.9	7.08	2.51	0.98	78.5	31.04	4.39	3.46
1.40	1.60	16.6	22.56	3.71	2.67	76.5	10.44	2.77	1.35	40.1	51.94	6.07	5.45
1.60	1.90	5.4	42.09	5.00	4.20	81.9	12.52	2.92	1.53	23.5	72.69	7.73	7.41
1.90		18.1	81.82	8.55	8.37	100.0	25.07	3.94	2.77	18.1	81.82	8.55	8.37

Head Sample: 14 Mesh X 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh X 0

25.61 4.29 2.73

TABLE E-4.

Freeman Coal Mining Corp.
Orient No. 6 Mine-No. 6 Seam
Jefferson County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	45.2	3.68	1.25	0.56	45.2	3.68	1.25	0.56	100.0	23.84	1.84	1.25
1.30	1.40	28.5	13.72	2.11	1.38	73.7	7.56	1.58	0.88	54.8	40.47	2.32	1.83
1.40	1.60	5.3	28.92	2.67	2.44	79.0	9.00	1.66	0.98	26.3	69.46	2.55	2.31
1.60	1.90	2.0	59.86	2.87	2.53	81.0	10.25	1.69	1.02	21.0	79.69	2.52	2.28
1.90		19.0	81.78	2.48	2.25	100.0	23.84	1.84	1.25	19.0	81.78	2.48	2.25

Head Sample: 1-1/2" X 100 Mesh = 98.5% of Raw Run of Mine Coal Crushed to 1-1/2"

24.15 1.76 1.20

100 Mesh X 0 = 1.5% of Raw Run of Mine Coal Crushed to 1-1/2"

23.63 2.05 1.68

TABLE E-5.

Freeman Coal Mining Corp.
Orient No. 6 Mine-No. 6 Seam
Jefferson County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	42.5	4.22	1.22	0.53	42.5	4.22	1.20	0.53	100.0	23.62	1.78	1.25
1.30	1.40	28.2	9.78	1.63	1.02	70.7	6.44	1.37	0.73	57.5	37.96	2.21	1.79
1.40	1.60	7.8	29.07	2.69	2.40	78.5	8.69	1.50	0.89	29.3	65.08	2.77	2.52
1.60	1.90	3.0	40.67	3.05	2.54	81.5	9.86	1.56	0.95	21.5	78.14	2.80	2.57
1.90		18.5	84.22	2.76	2.57	100.0	23.62	1.78	1.25	18.5	84.22	2.76	2.57

Head Sample: 3/8" X 100 Mesh = 98.4% of Raw Run of Mine Coal Crushed to 3/8"

23.75 1.80 1.22

100 Mesh X 0 = 1.6% of Raw Run of Mine Coal Crushed to 3/8"

34.09 1.86 1.55

TABLE E-6.

Freeman Coal Mining Corp.
Orient No. 6 Mine-No. 6 Seam
Jefferson County, Illinois

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	37.1	4.55	1.55	0.46	37.1	4.55	1.15	0.15	100.0	24.15	1.76	1.28
1.30	1.40	27.7	8.61	1.41	0.88	64.8	6.29	1.29	0.64	62.9	35.71	2.12	1.76
1.40	1.60	13.9	21.45	1.69	1.27	78.7	8.96	1.34	0.75	35.2	57.03	2.68	2.45
1.60	1.90	3.2	44.56	2.44	2.08	81.9	10.35	1.38	0.80	21.3	80.25	3.32	3.22
1.90		18.1	86.56	3.48	3.42	100.0	24.15	1.76	1.28	18.1	86.56	3.48	3.42

Head Sample: 14 Mesh X 0 = 100.0% of Raw Coal Sample Crushed to 14 Mesh

24.85 1.76 1.27

TABLE E-7.

Peabody Coal Company
Camp 1 & 2 Mines - No.9 Seam
Union County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	62.2	5.81	2.74	0.76	62.2	5.81	2.74	0.76	100.0	19.76	4.54	2.72
1.30	1.40	12.2	12.15	3.42	1.64	74.4	6.58	2.85	0.90	37.8	42.71	7.49	5.94
1.40	1.60	7.5	20.20	5.10	3.40	81.9	8.07	3.06	1.13	25.6	57.28	9.43	7.98
1.60	1.90	2.4	30.25	6.74	5.70	84.3	8.70	3.16	1.26	18.1	72.64	11.22	9.88
1.90		15.7	79.12	11.91	10.52	100.0	19.76	4.54	2.72	15.7	79.12	11.91	10.52

Head Sample: $1\frac{1}{2}$" x 100 Mesh = 98.4% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

19.87 4.53 2.84

100 Mesh X 0 = 1.6% of Raw Run of Mine Coal Crushed to 1-1/2"

26.63 3.75 2.20

TABLE E-8.

Peabody Coal Company
Camp 1 & 2 Mines - No.9 Seam
Union County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	47.3	3.94	2.55	0.53	47.3	3.94	2.55	0.53	100.0	20.05	4.54	2.93
1.30	1.40	21.1	9.68	3.07	1.28	68.4	5.71	2.71	0.76	52.7	34.51	6.33	5.09
1.40	1.60	11.4	20.18	4.50	3.05	79.8	7.78	2.97	1.09	31.6	51.09	8.51	7.63
1.60	1.90	4.8	31.04	6.38	5.65	84.6	9.10	3.16	1.35	20.2	68.54	10.78	10.21
1.90		15.4	80.23	12.15	11.63	100.0	20.05	4.54	2.93	15.4	80.23	12.15	11.63

Head Sample: $\frac{3}{8}$" x 100 Mesh = 97.1% of Raw Run of Mine Coal Crushed to $\frac{3}{8}$"

20.28 4.52 2.98

100 Mesh X 0 = 2.9% of Raw Run of Mine Coal Crushed to 3/8"

26.52 3.75 2.24

TABLE E-9.

Peabody Coal Company
Camp 1 & 2 Mines - No.9 Seam
Union County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	37.0	3.02	2.47	0.42	37.0	3.02	2.47	0.42	100.0	19.91	4.22	2.77
1.30	1.40	27.5	9.01	2.67	0.99	64.5	5.57	2.56	0.66	63.0	29.83	5.25	4.15
1.40	1.60	15.7	20.45	3.56	2.46	80.2	8.49	2.75	1.01	35.5	45.96	7.25	6.61
1.60	1.90	5.0	37.87	5.19	4.55	85.2	10.21	2.90	1.22	19.8	66.18	10.18	9.89
1.90		14.8	75.75	11.86	11.70	100.0	19.91	4.22	2.77	14.8	75.75	11.86	11.70
Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh							19.95	4.15	2.73				

Table E-10.

Weldon Coal Company
Weldon Mine - Des Moines No. 1 Seam
Marion County, Iowa

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	39.6	4.79	2.79	1.60	39.6	4.79	2.79	1.60	100.0	15.76	6.29	4.94
1.30	1.40	40.4	9.50	3.82	1.83	80.0	7.17	3.31	1.72	60.4	22.96	8.59	7.13
1.40	1.60	4.9	21.02	6.66	6.00	84.9	7.97	3.50	1.96	20.0	50.14	18.23	17.85
1.60	1.90	2.4	30.85	8.83	8.36	87.3	8.60	3.65	2.14	15.1	59.59	21.98	21.69
1.90		12.7	65.02	24.47	24.21	100.0	15.76	6.29	4.94	12.7	65.02	24.47	24.21

Head Sample: $1\frac{1}{2}$" x 100 = 98.8% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

	%Ash	Total	Pyr.
Head Sample	15.80	6.31	5.73
100 Mesh X 0	25.08	8.06	7.19

100 Mesh X 0 = 1.2% of Raw Run of Mine Coal Crushed to 1-1/2"

Table E-11.

Weldon Coal Company
Weldon Mine - Des Moines No. 1 Seam
Marion County, Iowa

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	37.9	3.75	2.54	1.54	37.9	3.75	2.54	1.54	100.0	14.75	6.20	5.32
1.30	1.40	35.5	7.55	3.57	2.57	73.4	5.59	3.04	2.04	62.1	21.47	8.43	7.63
1.40	1.60	8.9	18.30	5.24	4.20	82.3	6.96	3.28	2.27	26.6	40.04	14.92	14.39
1.60	1.90	3.7	20.85	6.34	5.47	86.0	7.56	3.41	2.41	17.7	50.97	19.79	19.52
1.90		14.0	58.93	23.35	23.23	100.0	14.75	6.20	5.32	14.0	58.93	23.35	23.23

Head Sample: $\frac{3}{8}$" x 100 = 96.5% of Raw Run of Mine Coal Crushed to $\frac{3}{8}$"

15.01 6.01 5.15

100 Mesh X 0 = 4.5% of Raw Run of Mine Coal Crushed to 3/8"

23.76 7.40 6.97

Table E-12.

Weldon Coal Company
Weldon Mine - Des Moines No. 1 Seam
Marion County, Iowa

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	48.2	6.08	3.27	1.97	48.2	6.08	3.27	1.97	100.0	14.76	6.04	4.93
1.30	1.40	32.5	9.11	4.02	2.84	80.7	7.30	3.57	2.32	51.8	22.83	8.62	7.68
1.40	1.60	7.3	18.13	6.45	5.69	88.0	8.20	3.81	2.60	19.3	45.94	16.37	15.83
1.60	1.90	2.0	35.74	8.30	7.92	90.0	8.81	3.91	2.72	12.0	62.86	22.40	22.00
1.90		10.0	68.28	25.22	24.82	100.0	14.76	6.04	4.93	10.0	68.28	25.22	24.82
Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh													
							15.54	5.88	4.85				

Table E-13.

Buffalo Coal Company
Walker Mine - Upper Kittanning Seam
Garrett County, Maryland

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	12.7	3.06	.67	.07	12.7	3.06	.67	.07	100.0	15.62	.70	.13
1.30	1.40	59.8	9.14	.63	.09	72.5	8.07	.64	.09	87.3	17.45	.70	.14
1.40	1.60	17.9	22.65	.77	.02	90.4	10.96	.66	.07	27.5	35.53	.87	.23
1.60	1.90	5.0	44.72	.62	.02	95.4	12.73	.66	.07	9.6	59.54	1.05	.63
1.90		4.6	75.65	1.51	1.30	100.0	15.62	.70	.13	4.6	75.65	1.51	1.30

Head Sample: $1\frac{1}{2}$" x 100 Mesh = 99.4% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

15.65 0.68 0.14

100 Mesh X 0 = 0.6% of Raw Run of Mine Coal Crushed to 1-1/2"

18.07 1.17 0.62

TABLE E-14.

Buffalo Coal Company
Walker Mine - Upper Kittanning Seam
Garret County, Maryland

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	13.3	2.88	.68	.10	13.3	2.88	.68	.10	100.0	15.52	.69	.14
1.30	1.40	50.7	7.76	.68	.11	64.0	6.75	.68	.11	86.7	17.46	.69	.14
1.40	1.60	24.9	20.33	.56	.01	88.9	10.55	.65	.08	36.0	31.13	.71	.19
1.60	1.90	6.0	41.22	.61	.01	94.9	12.49	.64	.08	11.1	55.36	1.04	.59
1.90		5.1	72.00	1.55	1.27	100.0	15.52	.69	.14	5.1	72.00	1.55	1.27

Head Sample: 3/8" x 100 Mesh = 97.7% of Raw Run of Mine Coal Crushed to 3/8"
15.85 0.71 0.14

100 Mesh X 0 = 2.3% of Raw Run of Mine Coal Crushed to 3/8"
16.18 0.93 0.49

Table E-15.

Buffalo Coal Company
Walker Mine - Upper Kittanning Seam
Garrett County, Maryland

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr
	1.30	9.9	3.00	.62	.14	9.9	3.00	.62	.14	100.0	15.63	.73	.14
1.30	1.40	46.0	6.18	.70	.10	55.9	5.62	.69	.11	90.1	17.02	.74	.14
1.40	1.60	30.0	16.98	.62	.01	85.9	9.59	.66	.07	44.1	28.33	.78	.17
1.60	1.90	8.2	39.22	.59	.00	94.1	12.17	.66	.07	14.1	52.48	1.13	.52
1.90		5.9	70.92	1.87	1.24	100.0	15.63	.73	.14	5.9	70.92	1.87	1.24

Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh

15.60 0.72 0.11

TABLE E-16.

Hanna Coal Company
Egypt Valley No. 21 Mine - Pittsburgh No. 8 Seam
Belmont County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	37.4	5.34	3.25	1.06	37.4	5.34	3.25	1.06	100.0	22.35	6.29	4.62
1.30	1.40	30.6	10.09	5.09	3.04	68.0	7.48	4.08	1.95	62.6	32.50	8.10	6.74
1.40	1.60	10.6	22.95	7.76	6.54	78.6	9.56	4.57	2.57	32.0	53.94	10.98	10.28
1.60	1.90	3.6	42.43	9.71	8.84	82.2	11.00	4.80	2.84	21.4	69.29	12.58	12.13
1.90		17.8	74.72	13.16	12.80	100.0	22.35	6.29	4.62	17.8	74.72	13.16	12.80

Head Sample: $1\frac{1}{2}$" x 100 Mesh = 99.1% of Raw Run of Mine Coal Crushed to 1-1/2"

22.58 6.30 4.64

100 Mesh X 0 = 0.9% of Raw Run of Mine Coal Crushed to 1-1/2"

26.30 5.61 3.96

Table E-17.

Hanna Coal Company
Egypt Valley No. 21 Mine - Pittsburgh No.8 Seam
Belmont County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				SUM. REJECT SINK			
				% Sul.				%Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	35.7	5.21	3.10	0.97	35.7	5.21	3.10	0.97	100.0	22.50	6.18	4.62
1.30	1.40	32.8	10.76	4.77	2.98	68.5	7.87	3.90	1.93	64.3	32.10	7.90	6.64
1.40	1.60	9.1	23.37	7.38	6.22	77.6	9.69	4.31	2.44	31.5	54.31	11.15	10.45
1.60	1.90	5.3	50.72	8.72	8.34	82.9	12.31	4.59	2.81	22.4	66.88	12.68	12.17
1.90		17.1	71.89	13.91	13.36	100.0	22.50	6.18	4.62	17.1	71.89	13.91	13.36

Head Sample: $\frac{3}{8}$" x 100 Mesh = 96.0% of Raw Run of Mine Coal Crushed to 3/8"

22.88 6.47 4.91

100 Mesh X 0 = 4.0% of Raw Run of Mine Coal Crushed to 3/8"

28.06 5.56 4.10

Table E-18.

Hanna Coal Company
Egypt Valley No. 21 Mine - Pittsburgh No. 8 Seam
Belmont County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	30.3	4.18	3.09	1.06	30.3	4.18	3.09	1.06	100.0	22.80	6.18	5.12
1.30	1.40	29.8	9.65	4.13	3.04	60.1	6.89	3.61	2.04	69.7	30.89	7.52	6.89
1.40	1.60	17.0	22.14	6.63	6.54	77.1	10.25	4.27	3.03	39.9	46.76	10.06	9.77
1.60	1.90	5.5	34.31	9.71	8.84	82.6	11.86	4.63	3.42	22.9	65.03	12.60	12.16
1.90		17.4	74.74	13.52	13.21	100.0	22.80	6.18	5.12	17.4	74.74	13.52	13.21

Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh

22.61 6.30 4.46

Table E-19.

Dixie Fuel Company
No. 1 Mine-Mason Seam
Harlan County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	27.7	3.06	1.80	0.35	27.7	3.06	1.80	0.35	100.0	10.88	3.07	1.73
1.30	1.40	56.5	8.11	2.34	0.95	84.2	6.45	2.16	0.75	72.3	13.88	3.55	2.26
1.40	1.60	6.1	16.28	5.28	4.12	90.3	7.11	2.37	0.98	15.8	34.50	7.88	6.93
1.60	1.90	2.6	18.27	4.73	3.50	92.9	7.43	2.44	1.05	9.7	45.96	9.52	8.69
1.90		7.1	56.10	11.27	10.59	100.0	10.88	3.07	1.73	7.1	56.10	11.27	10.59
Head Sample: 1-1/2" x 100 Mesh = 99.4% of Raw Run of Mine Coal Crushed to 1-1/2"													
							11.08	3.05	1.68				
100 Mesh X 0 = 0.6% of Raw Run of Mine Coal Crushed to 1-1/2"													
							14.97	2.60	1.33				

Table E-20.

Dixie Fuel Company
No. 1 Mine-Mason Seam
Harlan County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	46.1	3.42	1.96	0.50	46.1	3.42	1.96	0.50	100.0	10.59	3.13	1.73
1.30	1.40	33.2	7.04	2.38	0.92	79.3	4.94	2.14	0.68	53.9	16.72	4.13	2.79
1.40	1.60	9.0	13.06	4.38	3.06	88.3	5.76	2.36	0.92	20.7	32.25	6.94	5.79
1.60	1.90	4.3	20.10	4.89	3.69	92.6	6.43	2.49	1.05	11.7	47.02	8.91	7.89
1.90		7.4	62.66	41.24	10.33	100.0	10.59	3.13	1.73	7.4	62.66	11.24	10.33

Head Sample: $\frac{3}{8}$" x 100 Mesh = 96.9% of Raw Run of Mine Coal Crushed to 3/8"

10.64 3.17 1.86

100 Mesh X 0 = 3.1% of Raw Run of Mine Coal Crushed to 3/8"

13.16 2.81 1.54

Table E-21.

Dixie Fuel Company
No. 1 Mine-Mason Seam
Harlan County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	48.6	4.09	1.79	0.48	48.6	4.09	1.79	0.48	100.0	11.12	3.02	1.79
1.30	1.40	34.4	6.84	2.15	0.86	83.0	5.23	1.94	0.64	51.4	17.76	4.19	3.03
1.40	1.60	8.1	17.37	4.37	3.33	91.1	6.31	2.15	0.88	17.0	39.86	8.31	7.41
1.60	1.90	2.3	24.92	8.03	7.14	93.4	6.77	2.29	1.03	8.9	60.33	11.95	11.13
1.90		6.6	72.67	13.31	12.52	100.0	11.12	3.02	1.79	6.6	72.67	13.31	12.52
Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 mesh							11.12	3.11	1.93				

Table E-22.

Rochester & Pittsburgh Coal Company
Jane Mine-Lower Freeport Seam
Armstrong County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	57.8	5.17	1.02	0.60	57.8	5.17	1.02	0.60	100.0	20.62	1.59	1.24
1.30	1.40	17.3	13.24	1.84	1.46	75.1	7.03	1.21	0.80	42.2	41.79	2.36	2.11
1.40	1.60	6.6	24.03	3.90	3.67	81.7	8.40	1.43	1.03	24.9	61.62	2.72	2.57
1.60	1.90	3.9	41.32	4.11	3.98	85.6	9.90	1.55	1.16	18.3	75.18	2.30	2.17
1.90		14.4	84.35	1.81	1.68	100.0	20.62	1.59	1.24	14.4	84.35	1.81	1.68

Head Sample: $1\frac{1}{2}$" x 100 Mesh = 99.1% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

20.81 1.63 1.30

100 Mesh X 0 = 0.9% of Raw Run of Mine Coal Crushed to 1-1/2"

21.13 2.03 1.60

Table E-23.

Rochester & Pittsburgh Coal Company
Jane Mine-Lower Freeport Seam
Armstrong County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	63.3	4.78	0.64	0.27	63.3	4.78	0.64	0.27	100.0	19.12	1.73	1.40
1.30	1.40	13.1	12.93	1.05	0.84	76.4	6.18	0.71	0.37	36.7	43.85	3.58	3.34
1.40	1.60	5.4	24.29	2.99	2.50	81.8	7.37	0.86	0.51	23.6	61.02	4.99	4.73
1.60	1.90	3.7	44.13	3.67	3.31	85.5	8.96	0.98	0.63	18.2	71.92	5.58	5.39
1.90		14.5	79.01	6.07	5.92	100.0	19.12	1.72	1.40	14.5	79.01	6.07	5.92

Head Sample: $\frac{3}{8}$" x 100 Mesh = 98.0% of Raw Run of Mine Coal Crushed to $\frac{3}{8}$"

19.15 1.68 1.39

100 Mesh X 0 = 2.0% of Raw Run of Mine Coal Crushed to 3/8"

21.83 1.64 1.24

Table E-24.

Rochester & Pittsburgh Coal Company
Jane Mine-Lower Freeport Seam
Armstrong County, Pennsylvania

'Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	49.4	5.54	0.61	0.15	49.4	5.54	0.61	0.15	100.0	19.92	1.62	1.27
1.30	1.40	23.3	11.63	0.72	0.39	72.7	7.49	0.65	0.23	50.6	33.95	2.60	2.36
1.40	1.60	10.2	23.04	1.06	0.88	82.9	9.40	0.70	0.31	27.3	53.01	4.20	4.05
1.60	1.90	4.3	44.75	2.42	2.27	87.2	11.15	0.78	0.40	17.1	70.88	6.08	5.94
1.90		12.8	79.66	7.31	7.17	100.0	19.92	1.62	1.27	12.8	79.66	7.31	7.17

Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh

19.21 1.62 1.35

Table E-25.

C & K Coal Company
Fox Mine - Lower Kittanning Seam
Clarion County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	59.5	5.14	1.78	.91	59.5	5.14	1.78	.91	100.0	12.14	3.46	2.72
1.30	1.40	27.3	10.99	3.81	3.19	86.8	6.98	2.42	1.63	40.5	22.42	5.92	5.39
1.40	1.60	5.9	30.15	4.41	3.91	92.7	8.45	2.55	1.77	13.2	46.06	10.28	9.94
1.60	1.90	1.7	36.32	7.33	7.07	94.4	8.96	2.63	1.87	7.3	58.92	15.03	14.81
1.90		5.6	65.78	17.37	17.16	100.0	12.14	3.46	2.72	5.6	65.78	17.37	17.16

Head Sample: $1\frac{1}{2}$" x 100 Mesh = 99.4% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

12.40 3.41 2.85

100 Mesh X 0 = 0.6% of Raw Run of Mine Coal Crushed to 1-1/2"

15.27 4.14 3.64

Table E-26.

C & K Coal Company
Fox Mine - Lower Kittanning Seam
Clarion County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	57.4	4.60	1.46	.89	57.4	4.60	1.46	.89	100.0	12.50	3.27	2.71
1.30	1.40	27.6	16.24	3.54	2.93	85.0	8.38	2.14	1.55	42.6	23.14	5.71	5.17
1.40	1.60	6.9	21.30	3.93	3.39	91.9	9.35	2.27	1.69	15.0	35.82	9.71	9.29
1.60	1.90	2.3	24.59	4.98	4.59	94.2	9.72	2.34	1.76	8.1	48.20	14.63	14.31
1.90		5.8	57.56	18.45	18.17	100.0	12.50	3.27	2.71	5.8	57.56	18.45	18.17

Head Sample: $\frac{3}{8}$" x 100 Mesh = 97.7% of Raw Run of Mine Coal Crushed to $\frac{3}{8}$"

12.32 3.36 2.82

100 Mesh X 0 = 2.3% of Raw Run of Mine Coal Crushed to 3/8"

15.13 4.24 3.81

Table E-27.

C & K Coal Company
Fox Mine - Lower Kittanning Seam
Clarion County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	42.3	3.62	1.26	.50	42.3	3.62	1.26	.50	100.0	12.33	3.28	2.62
1.30	1.40	34.9	7.82	2.15	1.44	77.2	5.52	1.66	.92	57.7	18.71	4.76	4.18
1.40	1.60	12.3	19.48	3.42	2.97	89.5	7.44	1.90	1.21	22.8	35.38	8.75	8.38
1.60	1.90	4.1	38.19	4.20	3.91	93.6	8.78	2.00	1.32	10.5	54.00	14.99	14.72
1.90		6.4	64.13	21.91	21.64	100.0	12.33	3.28	2.62	6.4	64.13	21.91	21.64

Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh

12.17 3.52 2.85

Table E-28.

Duquesne Light Company
Warwick Mine, Sewickley Seam
Greene County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	14.0	4.73	0.80	0.30	14.0	4.73	0.80	0.30	100.0	37.23	1.31	0.95
1.30	1.40	40.8	11.09	1.16	0.53	54.8	9.47	1.07	0.47	86.0	42.52	1.39	1.06
1.40	1.60	6.6	25.88	2.27	1.95	61.4	11.23	1.20	0.63	45.2	70.89	1.60	1.54
1.60	1.90	3.2	51.63	2.34	2.32	64.6	13.23	1.25	0.71	38.6	78.58	1.49	1.47
1.90		35.4	81.02	1.41	1.39	100.0	37.23	1.31	0.95	35.4	81.02	1.41	1.39

Head Sample: $1\frac{1}{2}$" x 100 = 99.4% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$".

36.98 1.34 1.04

100 Mesh X 0 = 0.6% of Raw Run of Mine Coal Crushed to 1-1/2"

36.32 1.78 1.23

Table E-29.

Duquesne Light Company
Warwick Mine, Sewickley Seam
Greene County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	15.7	4.84	0.77	0.28	15.7	4.84	0.77	0.28	100.0	36.83	1.30	0.92
1.30	1.40	37.1	12.96	1.09	0.41	52.8	10.55	0.99	0.37	84.3	42.79	1.40	1.03
1.40	1.60	7.3	26.69	1.95	1.68	60.1	12.51	1.11	0.53	47.2	66.24	1.65	1.53
1.60	1.90	5.0	60.04	1.75	1.55	65.1	16.16	1.16	0.61	39.9	73.49	1.59	1.50
1.90		34.9	75.40	1.57	1.49	100.0	36.83	1.30	0.92	34.9	75.40	1.57	1.49

Head Sample: $\frac{3}{8}$" x 100 = 98.2% of Raw Run of Mine Coal Crushed to $\frac{3}{8}$".

36.91 1.27 1.04

100 Mesh X 0 = 1.8% of Raw Run of Mine Coal Crushed to 3/8"

36.63 1.39 1.07

Table E-30.

Duquesne Light Company
Warwick Mine, Sewickley Seam
Greene County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	12.4	4.57	0.48	0.25	12.4	4.57	0.48	0.25	100.0	36.77	1.30	0.97
1.30	1.40	33.1	11.17	0.90	0.30	45.5	9.37	0.79	0.29	87.6	41.33	1.42	1.07
1.40	1.60	15.1	23.77	1.33	0.77	60.6	12.96	0.92	0.41	54.5	59.64	1.74	1.54
1.60	1.90	7.6	49.38	1.77	1.59	68.2	17.02	1.02	0.54	39.4	73.39	1.89	1.84
1.90		31.8	79.13	1.92	1.90	100.0	36.77	1.30	0.97	31.8	79.13	1.92	1.90

Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 Mesh

36.71 1.28 0.94

Table E-31.

Consolidation Coal Co.
Humphrey No.7 Mine
Monongalia County, West Virginia

Raw Run of Mine Coal
FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	Ash	Total	Pyr	Wt.	%Ash	Total	Pyr.
	1.30	65.8	4.56	1.61	0.44	65.8	4.56	1.61	0.44	100.0	9.44	2.30	1.20
1.30	1.40	22.7	9.92	2.50	1.41	88.5	5.93	1.84	0.69	34.2	18.82	3.62	2.67
1.40	1.60	4.2	23.25	4.10	3.25	92.7	6.72	1.94	0.80	11.5	36.39	5.81	5.17
1.60	1.90	2.9	33.19	4.01	3.11	95.6	7.52	2.00	0.87	7.3	43.95	6.85	6.28
1.90		4.4	51.05	8.72	8.32	100.0	9.44	2.30	1.20	4.4	51.05	8.72	8.32

Head Sample: $1\frac{1}{2}$" x 100 = 97.9% of Raw Run of Mine Coal Crushed to $1\frac{1}{2}$"

9.61 2.50 1.40

100 Mesh X 0 = 2.1% of Raw Run of Mine Coal Crushed to 1-1/2"

14.40 3.93 2.74

Table E-32.

Consolidation Coal Co.
Humphrey No.7 Mine
Monongalia County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (DRY BASIS)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM. RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	68.5	4.31	1.73	0.73	68.5	4.31	1.73	0.49	100.0	9.78	2.47	1.36
1.30	1.40	17.9	9.27	2.65	1.64	86.4	5.34	1.92	0.73	31.5	21.66	4.07	3.25
1.40	1.60	3.9	21.68	4.18	3.49	90.3	6.04	2.02	0.85	13.6	37.98	5.98	5.37
1.60	1.90	3.9	33.89	3.57	2.94	94.2	7.20	2.08	0.93	9.7	44.53	6.64	6.13
1.90		5.8	51.68	8.70	8.27	100.0	9.78	2.47	1.36	5.8	51.68	8.70	8.27

Head Sample:3/8" x 100 = 96.1% of Raw Run of Mine Coal Crushed to 3/8"

9.73 2.53 1.42

100 Mesh x 0 = 3.9% of Raw Run of Mine Coal Crushed to 3/8"

13.94 3.75 2.63

Table E-33.

Consolidated Coal Co.
Humphrey No.7 Mine
Monongalia County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUM.RECOVERY FLOAT				CUM. REJECT SINK			
				% Sul.				% Sul.				% Sul.	
Sink	Float	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.	%Wt.	%Ash	Total	Pyr.
	1.30	55.9	3.77	1.46	0.41	55.9	3.77	1.46	0.41	100.0	9.61	2.48	1.29
1.30	1.40	31.7	8.30	1.93	1.01	87.6	5.41	1.63	0.63	44.1	17.02	3.78	2.40
1.40	1.60	6.2	21.11	4.46	3.37	93.8	6.45	1.82	0.81	12.4	39.30	8.51	5.94
1.60	1.90	1.8	34.44	6.09	5.64	95.6	6.97	1.90	0.90	6.2	57.48	12.56	8.51
1.90		4.4	66.91	15.21	9.68	100.0	9.61	2.48	1.29	4.4	66.91	15.21	9.68
Head Sample: 14 Mesh x 0 = 100.0% of Raw Run of Mine Coal Crushed to 14 mesh													
							9.82	2.54	1.38				

Appendix F

Organic Sulfur Removal Data

Note: The complete procedure used to treat these coals is contained in Section 4.5 of the report.

TABLE F-1

ORGANIC SULFUR REMOVAL DATA

EAGLE NO. 2, CAMP NOS. 1 & 2,AND ORIENT NO. 6 MINES

Mine, Seam, and Location	Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Eagle No. 2 Mine, Illinois No. 5 Seam, Gallatin County, Illinois	1	4.30	3.11	0.05	1.14	30.43	29.56	40.01	9799
	2	4.16 4.02	3.42 3.18	0.06	0.92 0.78	30.99	29.80	39.21	9710
	3	4.17	3.22 2.76	0.07 0.07	0.88 1.34	30.33	30.05	39.62	9856
	Average Treated	4.16 ±.140	3.07 ±.210	0.06 ±.012	1.18 ±.252	30.58 ± .356	29.80 ± .245	39.61 ± .400	9788 ± 73.5
	Average Untreated	4.29 ±.023	2.64 ±.154	0.04 ±.017	1.61 ±.156	26.53 ± .202	34.30 ± .610	39.17 ± .409	10566 ±186
Camp Nos. 1 & 2 Mines No. 9 Seam, Union County, (West) Kentucky	4	5.13	3.68	0.04	1.41	25.24	33.25	41.51	10500
	5	5.10	3.71	0.07	1.32	25.46	33.73	40.81	10615
	6	5.30	4.13	0.07	1.10	26.28	32.71	41.01	10375
	Average Treated	5.18 ±.107	3.84 ±.251	0.06 ±.017	1.28 ±.273	25.66 ± .548	33.23 ± .510	41.11 ± .361	10497 ±120
	Average Untreated	4.51 ±.049	2.80 ±.120	0.06 ±.00	1.65 ±.130	21.13 ± .387	35.86 ± .672	43.01 ± .680	11105 ±101
Orient No. 6 Mine, Herrin No. 6 Seam, Jefferson County, Illinois	1	1.85	1.37	0.00	0.48	24.73	30.71	44.56	10585
	2	1.85	1.41	0.00	0.44	24.86	29.39	45.75	10577
	3	1.79	1.29	0.00	0.50	24.05	30.51	45.44	10822
	Average Treated	1.83 ±.035	1.36 ±.061	0.00 ±.01	0.47 ±.071	24.55 ± .435	30.20 ± .711	45.25 ± .612	10661 ±139
	Average Untreated	1.66 ±.069	1.30 ±.084	0.00 ±.01	0.36 ±.109	22.51 ± .104	31.67 ± .307	45.82 ± .344	11163 ±3.2

TABLE F-2
ORGANIC SULFUR REMOVAL DATA
BELLE AYR, FOX, COLSTRIP, AND JANE MINES

Mine, Seam, and Location	Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Total	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Heat Content btu/lb
Belle Ayr Mine,	1	0.86	0.37	0.00	0.49	7.77	47.51	44.72	11797
Roland-Smith Seam,	2	0.80	0.24	0.00	0.56	7.76	45.40	46.84	11993
Campbell County,	3	0.71	0.33	0.00	0.38	7.81	47.32	44.87	12074
Wyom.	Average Treated	0.79 ±075	0.31 ±.066	0.00 ±.01	0.48 ±.100	7.78 ± .026	46.74 ± .167	45.47 ± .191	11955 ±142
	Average Untreated	0.76 ±.029	0.22 ±.017	0.00 ±.01	0.54 ±.035	7.5[illegible] ± .058	47.11 ±1.55	45.35 ±1.50	12034 ±74.5
Fox Mine,	1	4.12	3.83	0.01	0.28	16.45	34.04	49.51	12186
Lower Kittanning Seam,	2	4.07	3.74	0.00	0.33	16.30	35.66	48.04	12275
Clarion County,	3	4.19	3.85	0.03	0.31	16.72	34.98	48.30	12285
Pennsylvania	Average Treated	4.13 ±.060	3.79 ±.064	0.01 ±.015	0.33 ±.089	16.49 ± .212	34.89 ± .813	48.62 ± .784	12249 ±54.5
	Average Untreated	3.83 ±.038	3.09 ±.017	0.05 ±.015	0.69 ±.044	13.55 ± .031	38.33 ± .580	48.12 ± .560	12973 ±17.6
Colstrip Mine,	1	0.85	0.31	0.02	0.52	9.99	41.78	48.23	11653
Rosebud Seam,	2	0.97	0.37	0.02	0.58	11.01	38.72	50.27	10839
Rosebud County,	3	0.88	0.32	0.00	0.56	9.86	41.39	48.75	11631
Montana	Average Treated	0.90 ±.062	0.33 ±.032	0.01 ±.012	0.56 ±.071	10.28 ± .630	40.63 ±1.67	49.08 ±1.06	11374 ±463
	Average Untreated	1.01 ±.006	0.34 ±.015	0.00 ±.00	0.67 ±.019	10.38 ± .075	43.09 ± .733	46.53 ± .801	11591 ±67
Jane Mine	1	2.00	1.73	0.00	0.27	25.64	28.41	45.95	11013
Lower Freeport Seam,	2	2.17	1.75	0.00	0.42	25.54	27.90	46.56	11179
Armstrong County,	3	2.08	1.69	0.00	0.39	25.25	26.84	47.91	11139
Pennsylvania	Average Treated	2.08 ±.085	1.72 ±.031	0.00 ±.01	0.36 ±.079	25.48 ±86.6	27.71 ± .800	46.81 ±1.00	11110 ±86.6
	Average Untreated	1.85 ±.015	1.44 ±.048	0.002 ±.004	0.41 ±.051	21.75 ± .081	30.07 ± .289	48.18 ± .250	11932 ±38.2

Appendix G

Sieve Analysis Data

TABLE G-1

SIEVE ANALYSIS DATA

Coal	Sample	Starting Wt.	Mesh - U.S. Standard Sieve Series												Final Wt.	Wt. Lost
			+100		-100 +115		-115 +150		-150 +200		-200 +325		-325			
			Wt.[a]	%[a]	Wt.	%	Wt.	%	Wt.	%	Wt.	%	Wt.	%		
Edna Mine Wadge Seam	a	52.93	0.01	0.0	0.29	0.6	1.55	3.0	8.27	16.0	34.93	67.4	6.79	13.1	51.84	1.09
	b	53.61	0.00	0.0	0.28	0.5	1.57	3.0	8.26	15.7	35.80	68.2	6.59	12.6	52.50	1.11
Navajo Mine Nos. 6, 7, & 8 Seams	a	52.92	0.01	0.0	1.10	2.1	3.28	6.3	11.52	22.2	32.09	61.8	3.91	7.5	51.91	1.01
	b	53.76	0.04	0.0	0.89	1.7	3.16	6.0	11.92	22.5	32.83	62.0	4.14	7.8	52.98	0.78
Belle Ayr Mine Roland-Smith Seam	a	50.16	0.26	0.5	4.02	8.2	4.69	9.5	10.94	22.3	26.74	54.4	2.47	5.0	49.12	1.04
	b	49.47	0.15	0.3	3.76	7.8	4.70	9.7	10.63	22.0	24.33	50.4	4.73	9.8	48.30	1.17
Colstrip Mine Rosebud Seam	a	65.25	0.13	0.2	3.12	4.9	5.71	8.9	16.63	25.9	36.59	57.0	2.03	3.2	64.21	1.04
	b	68.69	0.13	0.2	3.03	4.5	5.82	8.6	16.15	24.0	37.59	55.8	4.62	6.9	67.34	1.35
Weldon Mine Des Moines #1 Seam	a	56.18	0.01	0.0	3.37	6.1	4.01	7.2	10.80	19.4	36.42	65.6	0.92	1.7	55.53	0.65
	b	56.03	0.04	0.0	0.46	0.8	1.34	2.4	6.74	12.2	43.95	79.6	2.66	4.8	55.19	0.84
Eagle No. 2 Mine Illinois No. 5 Seam	a	52.74	0.13	0.2	1.52	2.9	2.85	5.5	8.66	16.7	34.70	66.9	3.98	7.6	51.84	0.90
	b	57.68	0.15	0.3	1.70	3.0	3.07	5.4	8.92	15.7	38.53	68.0	4.32	7.6	55.69	0.99
Orient No. 6 Mine Herrin No. 6 Seam	a	54.45	0.09	0.2	2.93	5.5	4.24	7.9	9.91	18.4	33.44	62.2	3.11	5.8	53.72	0.73
	b	54.84	0.09	0.2	3.02	5.6	4.08	7.6	10.47	19.4	32.22	59.6	4.15	7.7	54.03	0.81
Camp Nos. 1 & 2 Mines No. 9(West Ky.) Seam	a	55.18	0.39	0.7	1.99	3.7	3.91	7.2	11.74	21.6	33.14	61.1	3.08	5.9	54.25	0.93
	b	53.18	0.41	0.8	1.87	3.6	3.52	6.7	10.26	19.7	31.88	61.0	4.27	8.2	52.21	0.97
Walker Mine Upper Kittanning Seam	a	41.15	0.03	0.0	0.96	2.4	2.00	5.0	7.46	18.6	28.09	70.1	1.54	3.8	40.08	1.07
	b	50.41	0.03	0.0	1.07	2.2	2.40	4.9	9.83	19.9	34.72	70.3	1.31	2.7	49.36	1.05
Egypt Valley #21 Mine Pittsburgh No. 8	a	52.20	0.02	0.0	0.52	1.0	1.61	3.2	8.64	17.0	38.37	75.4	1.72	3.4	50.88	1.32
	b	50.87	0.00	0.0	0.90	1.8	1.72	3.5	11.62	23.3	34.21	68.6	1.39	2.8	49.84	1.03
No. 1 (Dixie Fuel) ne Mason Seam	a	50.89	0.01	0.0	1.40	2.8	2.92	5.8	9.87	19.8	31.83	63.7	3.92	7.8	49.95	0.94
	b	51.61	0.01	0.0	1.41	2.8	2.93	5.8	10.13	20.1	32.39	64.2	3.58	7.1	50.45	1.16
Jane Mine Lower Freeport Seam	a	72.26	0.18	0.3	4.47	6.3	6.94	9.8	17.65	24.9	40.44	57.0	1.25	1.8	70.93	1.33
	b	66.97	0.11	0.2	3.24	4.9	4.64	7.0	12.55	19.0	42.79	64.9	2.59	3.9	65.92	1.05
Fox Mine Lower Kittaning Seam	a	53.85	0.02	0.0	0.55	1.0	2.37	4.5	16.05	30.6	31.58	60.3	1.88	3.5	52.40	1.45
	b	49.29	0.00	0.0	0.59	1.2	2.37	5.0	17.49	36.6	25.72	53.9	1.57	3.3	47.74	1.55
Warwick Mine Sewickly Seam	a	50.22	0.01	0.0	1.19	2.4	3.01	6.1	8.77	17.9	33.99	69.3	2.10	4.3	49.08	1.14
	b	51.01	0.08	0.2	1.52	3.0	3.08	6.1	8.12	16.1	34.89	69.3	2.65	5.3	50.34	0.67
Humphrey No. 7 Mine Pittsburgh Seam	a	52.17	0.02	0.0	0.47	1.0	3.85	7.9	13.12	27.0	29.84	61.3	1.35	2.8	48.65	3.52
	b	51.49	0.03	0.0	0.73	1.5	2.47	5.1	11.25	23.1	32.07	65.8	2.19	4.5	48.74	2.75

a) All weights are in grams and percents in w/w.

Appendix H

Methods Development and Trace Element Analysis Data

The purpose of the methods development phase of the program was to evaluate and set up the analytical methods to be used for coal trace elemental analysis for the elements Ag, As, B, Be, Cd, Cr, Cu, F, Hg, Li, Mn, Ni, Pb, Sb, Se, Sn, V, and Zn and to identify obvious and/or possible problem areas. Methods development involved the assessment of various dissolution methods for coal and coal ash, and the effect these procedures had on the subsequent analysis. Based on the results of this study, a scheme was devised and tested for the analysis of all elements using a combination of plasma ashing in conjunction with conventional atomic absorption, micro thermal analysis and colorimetric techniques.

Sample dissolution can conceivably be accomplished by decomposing and dissolving the coal and ash simultaneously with an oxidizing acid attack, such as the H_2SO_4 -HNO_3-$HClO_4$ method used by the National Bureau of Standards for their atomic absorption mercury analysis in coal (6), or by first oxidizing the coal matrix by ashing either at low or high temperature, and then dissolving the residue by some appropriate technique. This study utilized low temperature oxygen plasma ashing since high temperature ashing (e.g. 500°C in a muffle furnace) has been reported to be unusable since many of the more volatile elements such as As, Cd, Hg, Pb, Sb, Se, and Zn, are lost(3,7). The ash remaining after decomposition of the coal matrix is then dissolved and the analysis performed. Since quantitative dissolution techniques vary with differing elemental and molecular composition, a search for a common dissolution procedure for the elements of interest was made utilizing readily available literature(4-8). Because the majority of the compounds normally associated with coal ash are oxides, silicates or sulfides, conventional dissolution methods for these classes of compounds, such as HF attack in conjunction with either H_2SO_4, $HClO_4$ or HNO_3 for silicates (6,7) and $LiBO_2$fusion for oxides (8), were given first consideration. The final evaluation was performed using 100 mesh x 0 Lower Kittanning coal and the five dissolution methods discussed below. One procedure was a chemical digestion using H_2SO_4-HNO_3-$HClO_4$(6) while the remaining four methods involved the dissolution of the low temperature ashing residue and included: (1) Na_2CO_3 fusion followed by HNO_3

dissolution of the melt, (2) direct HNO_3 attack, (3) $LiBO_2$ fusion followed by HNO_3 dissolution of the melt, and (4) HNO_3-HF digestion. All residues from the above digestions were filtered, washed, and dry ashed. These residues were then weighed and analyzed qualitatively by either X-ray fluorescence or electron beam microprobe. The results of these qualitative analyses showed that of the five methods used only two, HNO_3-HF and $LiBO_2$ fusion followed by HNO_3 dissolution of the melt, were effective in dissolving all of the elements of interest. Of these two methods the HNO_3-HF method was chosen as the preferred method.

The elemental analysis of the dissolved coal and coal ash samples was done by atomic absorption spectrophotometry (AA), using either flame or flameless techniques with some auxiliary methods being employed for As, B, and F. Atomic absorption as a general analytical tool is normally considered free of interelement interferences and, because of the large dilutions normally employed, is usually unresponsive to matrix changes. Trace elemental analysis in coal does not follow general rules since the elements of interest are present in a very dilute form in a relatively concentrated matrix, consisting of the major inorganic components of the coal ash as well as the relatively high concentrations of fluxes and acids needed for the dissolution. In preparation for the analysis a search was made of readily available literature for known interferents for each element and the techniques employed for their removal. This data is compiled in Table H-1 along with the expected detection limit for each element based on a 2 g sample dissolved in 100 ml of solution.

Since the predominant type of interference for the majority of the elements reported in the literature is molecular absorption, the sample background absorption was monitored for each element using a hydrogen continuum lamp with a wavelength close to the analytical wavelength (Table H-2). An evaluation of the analytical and background absorption data generated by the analysis of the five solutions encompassing different dissolution procedures showed significant background signals to be present for the majority of the elements using the $LiBO_2$-HNO_3, HNO_3-H_2SO_4-$HClO_4$, and the

TABLE H-1

ATOMIC ABSORPTION BACKGROUND FOR TRACE ELEMENTAL ANALYSIS

Detection Limit (ppm) Based on 2g Sample/100cc	Reported Interferences	Methods of Interference Removal
0.25 flameless (10µl aliquot)	In flameless method-H_2O vapor, organics or large excess of reducible cations.	Drier, heated spectrophotometer cell, excess of $SnCl_2$
.025 flame	None reported.	-
1.5 flame 0.1 flameless	200 ppm Ni, Cr, Mo, Si gave slight interference, $PO_4^{\equiv}$, $SO_4^{=}$, formate, phthalate	Use EDTA
0.15 flame	Molecular adsorption by Ca, Mg, Na, K, and Fe	Use background correction.
0.5	Fe, Cr, Ca molecular adsorption	Use background correction or N_2O-actylene flame.
5. flame 1.0 flameless	H_3PO_4	
0.15 flame	Si, and molecular absorbance by K, Na, Cr	Ca at 2000 ppm or use background correction
0.25 flame	Ni, Fe, pH	N_2O-actylene flame or addition of 2% NH_4Cl
5.0 flame 1.0 flameless 0.2 gas evolution	None reported	-
0.25 flame	Ca molecular adsorption	Use background correction

TABLE H-1 (Continued)

ATOMIC ABSORPTION BACKGROUND FOR TRACE ELEMENTAL ANALYSIS

Detection Limit (ppm) Based on 2g Sample/100cc	Reported Interferences	Methods of Interference Removal
0.15 flame	Ca, Na, K, Mg, and Fe molecular absorptions	Use background correction.
5.0 flame 1.0 flameless	Slight 1000 ppm Cu	
0.25 flame	Th, H_2SO_4, H_3PO_4	Keep sample well diluted
0.1 flame	Sr at 50 mg/ml	
2.5 flame 1.0 flameless	H_2SO_4, H_3PO_4, 5000 ppm Na	Keep acid concentration constant.
0.1	Colorimetric method - none reported	
0.06 gas evolution (10cc aliquot)	Colorimetric method H_2S	Pb acetate trap for sulfide removal
0.05	Colorimetric (curcumin) method NO_3^-, F^-	Separation might be called for.

TABLE H-2

ATOMIC ABSORPTION ANALYTICAL PARAMETERS

(A) Flame Methods

Element	Analytical(Å)	Slit(Å)	Background(Å)	Slit(Å)	Flame Conditions
Mn	2795	4	2882	4	Air-Acetylene
Cu	3247	10	3171	10	Air-Acetylene
Cr	3579	4	3563	4	N_2O-Acetylene
Ni	2320	2	2316	2	N_2O-Acetylene
Sn	2246	4	2186	4	hydrogen-Air
Ag	3281	10	3257	10	Air-Acatylene-lean
Sb	2176	4	2241	4	Air-Acetylene-lean
V	4408	2	-	-	N_2O Acetylene-emission mode
Pb	2833	10	2850	10	Air-Acetylene-lean
Cd	2288	4	2297	4	Air-Acetylene-lean
Zn	2139	10	2197	10	Air-Acetylene-lean
Li	6708	10	6698	10	Air-Acetylene-lean
Be	2349	10	2312	10	N_2O-Acetylene

B) flameless AA methods

Hg	2537	10	-	-	Ar flow, 2 SCFH, use 10cm cell heated to 200°C
Sb	2176	10	2241	10	Dry at instrument setting of 50 for 2 min atomize at setting of 80 for 1 sec at Ar flow of 14 SCFH
Se	1960	10	1879	10	Same settings as for Sb, except for addition of H_2 whose flow is regulated at 10 psig
Sn	2863	4	2840	4	Same setting as for Sb

Na_2CO_3-HNO_3 dissolution procedures. The HNO_3-HF procedure was found to be virtually free of background absorption, with the exception of Cd for which a small background signal was found.

H.1. Atomic Absorption Analysis Procedures

Analyses of Ag, Be, Cd, Cr, Cu, Li, Mn, Ni, Pb, Sb, Se, Sn, V, and Zn were all performed by atomic absorption methods on a single sample of coal ash. A 2g sample of coal in a Petri dish was placed in an International Plasma Corporation Model 1001B plasma asher and ashing begun. Approximately once every 4 hours the console was opened and the coal stirred to expose fresh surfaces. Ashing was continued 2-3 days until no black particles remained.

The ash was then transferred into a Parr Instrument Co. Model 4745 24 ml Teflon acid digestion bomb using repeated deionized water washings. After the volume was adjusted to approximately 10 ml, 2 ml of conc. HNO_3 (70% w/w Ultrex high purity) were added, and the solution was heated on a low-heat hot plate for 2 hours. An additional 2 ml conc. HNO_3 and 2.5 ml conc. HF (52% w/w, Ultrex high purity) were then added and the bomb was assembled. The bomb was then placed in an oven at $130^{o} \pm 5^{o}C$ for 4 hours. After cooling, the solution was filtered (if necessary) into a 100 ml volumetric flask. After adjusting the volume to 100 ml the solution was transferred to a polyethylene bottle for storage.

In all cases the glassware used was carefully cleaned with dilute HNO_3 followed by repeated rinsings with deionized water and a final rinsing with acetone. All glassware was then stored in a specially covered area until needed. Transfer to polyethylene containers was accomplished as soon as possible to minimize absorption on the walls of the glass containers. If storage was required at any time the solutions were refrigerated.

The solutions prepared in the above fashion were analyzed directly for 14 trace elements on a Fisher Scientific Co. Model 810 atomic absorption spectrophotometer (AA) using the operating conditions listed in Table H-2. The background wavelengths listed in Table H-2 were used to monitor for possible interfering molecular absorptions. Since the dual channel feature of the instrument allows simultaneous readings at the analytical and background wavelengths for these purposes, appropriate selection of flame conditions was used to eliminate possible interelement effects. It was necessary to apply corrections only in the case of Cd and on occasion for Be and Mn. Analysis for V was somewhat unsatisfactory by either atomic absorption or flame emission methods. Flame emission was used throughout the study for V and potential problems with this analysis are discussed below.

Analyses for Sb, Se, and Sn were performed using a Fisher Scientific Company Model 2 micro thermal analyzer attachment to the AA since flame analysis methods were felt to be too insensitive to this study. The detection limit for Se and Sn was still 2.5 ppm as opposed to the desired 1 ppm; however, the cost of achieving a lower analysis limit for these two elements was judged to be unwarranted in view of the probable additional costs involved. For all of the analyses using the micro thermal atomizer, background corrections were applied and standard additions of the element of interest were used for quantitative work. In most cases these three elements were not found in the samples studied.

H.2. Analysis Procedures for As, B, F and Hg

Separate analytical procedures had to be utilized for As, B, F and Hg due to the facts that AA is too insensitive for As and B, Hg is reported to be lost during plasma ashing (6), and AA techniques are not applicable to F.

The procedure chosen for As is a modified U. S. Bureau of Mines procedure (1,9,10). A 1 g sample of coal is mixed with 1 g of MgO in a porcelain crucible. The crucible is then heated slowly to 650°C and held for 1-1/2 hrs. The residue is transferred to a 125 ml Erlenmeyer flask using acidified water. To this solution is added 5 ml conc. HCl, 2 ml KI solution, and 1 ml of $SnCl_2$ solution and the mixture is allowed to stand for 15 min. This flask is connected to a receiving flask via a tube containing glass wool to which a few drops of lead acetate solution has been added. Ten ml of a solution of 5g silver diethyldithiocarbamate in 1000 ml pyridine is added to the receiver and 3g zinc to the reaction flask. After allowing 30 min for complete arsine gas evolution the absorbing solution is transferred to a 1 cm cell where its absorbance is measured at 540 mμ against the neat reagent using a Beckman DKII spectrophotometer. The arsenic concentration is calculated after referral to a calibration curve generated using a standard arsenic solution.

A colorimetric procedure is also used for B (11). A 1 g sample of coal in a platinum crucible is ashed in a muffle furnace at 550°C for 1 hr. The ash is fused with 1 g Na_2CO_3 and then taken into solution with 1 N HCl and diluted to 100 ml. Then 2 ml of this solution in a 10 ml Nalgene centrifuge tube is extracted with 2 ml of 10% chloroform solution of 2-ethyl-1, 3-hexandiol. The organic phase is then separated and added to a 50 ml Nalgene volumetric flask with 1 ml of a 0.375% (w/v) solution of curcumin in glacial acetic acid and 0.3 ml of conc. H_2SO_4. After allowing 15 min for color development the sample is diluted to 50 ml with 95% ethanol and the absorbance read at 550μ against 95% ethanol on a Beckman Model DKII spectrophotometer. A reagent blank is also run and subtracted from the sample reading. The B concentration is then determined using a calibration curve.

The analysis procedure for Hg is one currently in use by the U.S. Bureau of Mines (4). A 0.5g coal sample in a ceramic crucible is placed in a Leco Instrument Co. tube furnace at 450°C fitted to maintain an O_2 flow rate of 0.5 ℓ/min. The combustion gases are swept through an unheated quartz tube packed with 10g of gold foil for amalgamating the Hg vapor. After the initial combustion is complete (about 7 min) the temperature is increased to 650°C for 3 min. The gold foil trap is then fitted with an Ar purge at 1 ℓ/min and heated to 850°C for 15 sec. The Hg vapor released from the foil is swept into a 10 cm quartz cell positioned in the atomic absorption spectrophotometer and Hg is determined using the conditions in Table H-1. Calibration is accomplished using known volumes of Hg saturated air in the analysis procedure.

Fluorine in coal was determined using an automated complexone method. In preparation for the analysis an 0.5 g sample of coal is mixed with 1 g CaO in a nickel crucible and ashed at 600°C for 2 hours. The sintered cake is then fused with 2 G NaOH, dissolved in water and diluted to 250 ml. This solution is then ready for analysis by the standard procedure in which fluoride reacts with the red cerous chelate of alizarin complexion to produce a color which is measured spectrophotometrically at 624 mμ.

H.3. Procedure Assessment

In order to determine the adequacy of the analysis procedures, arrangements were made for TRW to participate in a round-robin concerned with trace elements in coal. This was conducted by the National Bureau of Standards under EPA contract. The National Bureau of Standards prepared a standard coal for mercury and submitted samples of this coal to a number of laboratories around the country for trace element determinations. A sample of this coal was sent to TRW and analyzed for the various trace elements using the procedures described above.

Table H-3 contains the TRW results obtained on the NBS coal. Included in the table are the analysis values reported by the Illinois Geological Survey using INAA. In general the TRW analyses are in fair agreement with those reported by IGS except in the cases of F, Ni, Pb, and Sn. For Ni, Pb, and Sn there are possible matrix effects that may have been responsible for the poor agreement. The lack of agreement in the F determinations could not be resolved.

H.4. Analysis Results

The results of trace element analyses for 18 elements in ten coals before and after treatment by the Meyers process are presented in Tables H-4 to H13. All analyses were run in triplicate on both untreated and treated coals in order to get a good estimate of precision of the results and a reliable estimate of the trace element removal. These analyses were run on three separate samples of untreated coal in order that all sources of error such as sampling, ashing, dissolution, handling, and final analysis would be included in the final precision estimate. In a similar manner, three separately extracted coal samples were each analyzed once for the three values on the treated coal.

A standard deviation was then calculated for each set of results and this was used to determine which results should be discarded. A value falling outside 2σ of the mean was not used. Discarded values are in parentheses in the data tables. The differences between the initial average value and the final average value are also presented in the tables. The deviations on the differences were calculated using Equation 1:

$$\sigma_{a-b} = \sqrt{\sigma_a^2 + \sigma_b^2} \qquad (1)$$

Also reported are the calculated % removals. The standard deviation for the amount removed was calculated using Equation 2:

$$\sigma_{(a-b)/a} = \sqrt{\frac{b^2}{a^4} \cdot \sigma_a^2 + \frac{1}{a^2} \cdot \sigma_b^2} \qquad (2)$$

In cases where $\sigma_{(a-b)/a}$ is larger or the same as the value of the % difference N.D. is entered in the % change column to indicate that any apparent difference in the initial and final values is not statistically valid. In all cases where the element was not detected in the starting coal "Ind" appears in the ppm change and % change column.

TABLE H-3
TRACE ELEMENT ANALYSIS (PPM)
NBS STANDARD COAL

Element	Determined				Reported	
	1	2	3	Average	IGS	NBS
Ag	4.6	0.5	<.5	1.7±2.5	<4	-
As	3.7	3.9	3.7	3.8±0.1	5.7	5.9±0.4
B	25.5	20.4	20.4	22.1±2.9	43	-
Be	1.5	3.6	1.0	2.0±1.4	-	-
Cd	0.5	2.0	1.5	1.3±0.8	<.4	0.19
Cr	33	35	36	35±1.5	22	22±2
Cu	25	21	20	22±2.6	28	18±2
F	173	133	138	148±21.8	80	83
Hg	0.25	0.25	0.31	0.27±0.03	0.17	.11
Li	22	30	33	28±5.7	-	-
Mn	36	42	39	39±3.0	38	47±3
Ni	26	20	30	25±5.0	26	15±1
Pb	2.6	5.1	7.6	5.1±2.5	24	30±9
Sb	<1	<1	1	1	-	-
Se	5.0	5.0	10.0	6.7±2.9	2.8	2.8±0.2
Sn	<2.5	<2.5	<2.5	<2.5	9.6	-
V	40	66	71	59±16.6	54	35±4
Zn	53	47	45	48±4.2	-	37±4

TABLE H-4

TRACE ELEMENT ANALYSIS (PPM)

COLSTRIP MINE, ROSEBUD SEAM, ROSEBUD CO., MONTANA

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	Ind	Ind
As	<.01	<.01	<.01	0.01	<.01	<.01	<.01	<.01	Ind	Ind
B	40	32	32	5	5	-	35 ± 4.6	5 ± 0	-30 ± 4.6	-86 ± 2
Be	0.5	0.5	0.5	<.5	<.5	<.5	0.5	<.5	Ind	Ind
Cd	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cr	<.5	<.5	<.5	5	10	5	<.5	>±2.9	+6.5 ± 2.9	Gain
Cu	6	8	9	55	55	62	8 ± 1.5	57 ± 4.0	+49 ± 4.3	Gain
F	20	20	46	21.6	30.0	-	29 ± 15	26 ± 5.3	-3 ± 16	N.D.
Hg	0.16	0.27	0.16	0.17	0.13	-	0.20 ± 0.06	0.15 ±0.03	-0.05 ±0.07	N.D.
Li	3	4	4	18	19	22	4 ± 0.6	20 ± 2.1	+16 ± 2.2	Gain
Mn	79	87	96	6	4	8	87 ± 8.5	6 ± 2.0	-81 ± 8.7	-93 ± 3
Ni	34	28	32	14	12	12	31 ± 3	13 ± 1.1	-18 ± 3.2	-58 ± 5
Pb	4	<.5	4	<.5	.5	<.5	3 ± 2.3	0.2 ± 0.3	-2.8 ± 2.3	-93 ± 11
Sb	1	<1	1	<1	<1	<1	1	<1	Ind	Ind
Se	(14)	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	98	120	90	<5.	20	<5.	103 ± 15.5	<7 ± 11.5	-96 ± 19.3	-93 ± 11
Zn	18	6	4	13	11	12	9 ± 7.6	12 ± 1	+3 ± 7.7	N.D.

TABLE H-5
TRACE ELEMENT ANALYSIS (PPM)
EAGLE NO. 2 MINE, ILLINOIS NO. 5 SEAM, GALLATIN CO., ILLINOIS

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	<.1	<.1	<.1	13	15	6	<.1	11 ± 4.7	+11 ± 4.7	Gain
As	6.0	7.7	6.0	<.01	1.9	<.01	6.6 ± 1.0	0.6 ± 1.1	-6.0 ± 1.5	-91 ± 17
B	28	28	33	32	32	-	30 ± 2.9	32 ± 0	+2 ± 2.9	N.D.
Be	0.5	0.5	0.5	<.5	<.5	<.5	0.5	<0.5	Ind	Ind
Cd	<.5	0.5	1.0	<.5	<.5	<.5	0.5 ± 0.5	<0.5	Ind	Ind
Cr	130	124	124	40	32	(130)	126 ± 3.5	36 ± 5.6	-90 ± 6.6	-71 ± 5
Cu	18	14	23	38	38	43	18 ± 4.6	40 ± 2.9	+22 ± 5.4	Gain
F	152	152.	50	150	164	-	151 ± 1.1	157 ± 9.9	+6 ± 10	N.D.
Hg	0.11	0.20	-	0.14	0.14	0.23	0.16 ± 0.06	0.17 ± 0.05	+0.01 ± 0.08	N.D.
Li	4	4	4	15	18	18	4 ± 0.1	17 ± 1.7	+13 ± 1.7	Gain
Mn	88	86	86	15	18	27	86 ± 1.0	20 ± 6.2	-66 ± 6.3	-77 ± 7
Ni	128	138	142	35	47	58	136 ± 7.2	47 ± 11.5	-89 ± 13.6	-65 ± 10
Pb	40	25	23	0.6	<.5	<.5	29 ± 9.3	<.5	-28.5 ± 9.3	-98 ± 1
Sb	<1	1	1	5	<1	7.5	1 ± 0	4 ± 3.8	+3 ± 3.8	Gain
Se	5	<2.5	5	<2.5	<2.5	<2.5	4 ± 2.3	<2.5	> -1.5 ± 2.3	> 38 ± 36
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	39	47	105	100	100	70	64 ± 36	90 ± 17	+26 ± 40	N.D.
Zn	207	218	219	34	32	36	215 ± 6.6	34 ± 2.0	-181 ± 6.9	-84 ± 1

TABLE H-6

TRACE ELEMENT ANALYSIS (PPM)

ORIENT NO. 6 MINE, HERRIN NO. 6 SEAM, JEFFERSON CO., ILLINOIS

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	Ind	Ind
As	15.8	14.5	(2.8)	2.0	1.4	2.4	15.2 ± 0.9	1.9 ± 0.5	13.3 ± 1.0	-88 ± 3
B	38	44	47	30	30	30	43 ± 4.6	30 ± 0	-13 ± 4.6	-30 ± 8
Be	8.0	3.0	8.0	0.5	0.5	0.5	6 ± 2.9	0.5 ± 0	-5.5 ± 2.9	-92 ± 48
Cd	0.5	0.5	1.0	0.5	<.5	<.5	0.7 ± 0.3	0.2 ± 0.3	-0.5 ± 0.4	-71 ± 45
Cr	79	72	72	55	61	56	74 ± 4.0	57 ± 3.2	-17 ± 5.1	-23 ± 6
Cu	39	39	30	<.5	<.5	<.5	36 ± 5.2	<0.5 ± 0	-36 ± 5.2	-100 ± 11
F	104.0	104.0	107.0	90.7	91.2	89.7	105 ± 1.7	90.5 ± 0.8	-14.5 ± 1.9	-14 ± 2
Hg	0.15	0.09	0.11	0.13	-	0.16	0.12 ± .02	0.14 ± .02	+0.02 ± 0.03	N.D.
Li	22	24	22	4	6	5	23 ± 1.2	5 ± 0.6	-18 ± 1.3	-78 ± 3
Mn	46	60	66	3	3	12.	57 ± 10.3	6 ± 5.4	-51 ± 11.6	-89 ± 10
Ni	50	50	60	105	110	101	53 ± 5.8	105 ± 4.5	+52 ± 7.3	Gain
Pb	<1	1.5	<1	48	128	48	0.5 ± 0.9	75 ± 46	+74 ± 46	Gain
Sb	<1	<1	<1	1.0	1.0	1.5	<1	1.2 ± 0.3	Ind	Ind
Se	5.0	<2.5	10.0	<2.5	<2.5	5.0	5 ± 5	2 ± 3	-3 ± 5.8	N.D.
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	75	35	20	69	79	58	43 ± 28	69 ± 10.5	+26 ± 30	N.D.
Zn	138	144	136	22	22	30	139 ± 4.2	25 ± 4.6	-114 ± 6.2	-82 ± 4

TABLE H-7

TRACE ELEMENT ANALYSIS (PPM)

CAMP NOS. 1 AND 2 MINES, NO. 9 SEAM, UNION CO., WEST KENTUCKY

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	9.0	5.0	11.0	5	2	6	8 ± 3.1	4 ± 2.1	-4 ± 3.7	50 ± 33
As	6.0	5.4	5.8	0.7	0.8	1.6	5.7 ± 0.3	1.0 ± 0.5	-4.7 ± 0.6	-82 ± 9
B	259	298	260	35	-	35	272 ± 22.2	35 ± 0.0	-237 ± 22.2	-87 ± 1
Be	1.0	3.0	0.5	0.5	0.5	0.5	1.5 ± 1.2	0.5 ± 0.0	-1 ± 1.2	67 ± 27
Cd	1.0	1.0	0.5	0.5	<.5	<.5	0.8 ± 0.3	-0.6 ± 0.4	- 0.2 ± 0.5	N.D.
Cr	125	120	120	70	101	30	122 ± 2.9	67 ± 36	-55 ± 36	-45 ± 30
Cu	18	17	15	11	10	18	17 ± 1.5	13 ± 4.4	-4 ± 4.7	23 ± 27
F	193	210	210	241	110	169	215 ± 24.3	173 ± 65.6	-42 ± 70	N.D.
Hg	0.12	0.21	0.16	0.20			0.16 ± 0.04	0.20	0	N.D.
Li	10.5	10.5	10.5	1.5	1.2	0.2	10.5 ± 0	1.0 ± 0.7	-9.5 ± 0.7	-90 ± 7
Mn	100	97	98	7	3	2	98 ± 1.5	4 ± 2.6	-94 ± 3.0	-96 ± 3
Ni	35	35	10	118	110	32	27 ± 14.4	87 ± 47.5	+60 ± 50	Gain
Pb	30	20	25	11	50	33	25 ± 5	31 ± 19.6	+6 ± 20	N.D.
Sb	<1	<1	<1	3	2.5	<1	<1	1.8 ± 1.6	>+0.8 ± 1.6	N.D.
Se	<2.5	<2.5	<2.5	12	5	2	<2.5	7 ± 5.2	+4.5 ± 5.2	N.D.
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	120	120	75	125	55	30	105 ± 26	70 ± 49.2	-35 ± 56	N.D.
Zn	94	92	104	32	36	63	97 ± 6.4	44 ± 16.9	-53 ± 18	-55 ± 18

TABLE H-8

TRACE ELEMENT ANALYSIS (PPM)

EGYPT VALLEY NO. 21 MINE, PITTSBURGH NO. 8 SEAM, BELMONT CO., OHIO

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	4	4	4	3	2	2	4 ± 0	2 ± 0.6	-2 ± .6	-50 ± 15
As	23.9	21.0	21.7	3.4	1.9	4.8	22.2 ± 1.5	3.4 ± 1.4	-18.8 ± 2.1	-85 ± 6
B	34	34	-	35	35	-	34 ± 0	35 ± 0	-1 ± 0	N.D.
Be	0.6	0.8	0.6	0.3	0.5	0.4	0.7 ± 0.1	0.4 ± 0.1	-0.3 ± 0.1	-43 ± 16
Cd	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cr	52	56	57	50	56	54	55 ± 2.6	53 ± 3	-2 ± 4.0	N.D.
Cu	28	25	25	19	15	17	26 ± 1.7	17 ± 2	-9 ± 2.6	35 ± 9
F	159	177	-	141	124	-	168 ± 12.7	132 ± 12	-36 ± 17	-21 ± 9
Hg	0.35	0.27	0.32	0.48	0.19	0.33	0.31 ± 0.04	0.33 ± 0.14	+0.02 ± 0.15	N.D.
Li	26	26	26	25	26	26	26 ± 0	26 ± 0.6	0 ± .6	N.D.
Mn	40	42	40	17	16	16	41 ± 1.2	16 ± 0.6	-25 ± 1.3	-61 ± 2
Ni	41	42	40	18	22	20	41 ± 1	20 ± 2	-21 ± 2.2	-51 ± 5
Pb	14	16	15	5	5	6	15 ± 1	5 ± 0.6	-10 ± 1.2	-67 ± 5
Sb	<1	<1	<1	<1	<1	<1	<1	<1	Ind	Ind
Se	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	90	110	105	65	65	65	102 ± 10.4	65 ± 0	-37 ± 10	-36 ± 7
Zn	32	31	31	10	11	9	31 ± 0.6	10 ± 1	-21 ± 1.2	-68 ± 4

TABLE H-9
TRACE ELEMENT ANALYSIS (PPM)
JANE MINE
LOWER FREEPORT SEAM, ARMSTRONG CO., PENNSYLVANIA

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	1	2	2	6	4	<.1	2 ± 0.6	3 ± 3	+1 ± 3.1	N.D.
As	28.8	29.0	29.0	6.1	3.3	7.4	28.9 ± 0.1	5.6 ± 2.1	-23.3 ± 2.1	-81 ± 7
B	25	26	29	8	8	-	27 ± 2.1	8 ± 0	-19 ± 2.1	-70 ± 2
Be	0.8	1.0	0.5	<.5	<.5	<.5	0.8 ± 0.3	<.5	>-.3 ± .3	>-38
Cd	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cr	54	54	58	30	20	15	55 ± 2.3	22 ± 7.6	-33 ± 7.9	-60 ± 14
Cu	35	35	36	32	30	30	35 ± 0.6	31 ± 1.2	-4 ± 1.3	-11 ± 4
F	128	116	-	213	112	-	122 ± 8.4	162 ± 71.4	+40 ± 72	N.D.
Hg	0.13	0.12	0.08	0.14	0.15	0.09	0.11 ± 0.03	0.13 ± 0.03	+0.03 ± 0.04	N.D.
Li	38	38	39	3	3	2	38 ± 0.6	3 ± 0.6	-35 ± 0.8	-92 ± 2
Mn	46	45	47	3	8	6	46 ± 1.0	6 ± 3.0	-40 ± 3.2	-87 ± 7
Ni	32	34	32	45	44	27	33 ± 1.2	39 ± 10.1	+6 ± 10.2	N.D.
Pb	22	22	30	<.3	0.4	0.3	25 ± 4.6	0.2 ± 0.2	-25 ± 4.6	-99 ± 2
Sb	<1	<1	<1	<1	<1	<1	<1	<1	Ind	Ind
Se	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	120	145	175	135	140	185	147 ± 28	153 ± 28	+6 ± 40	N.D.
Zn	34	35	32	22	21	9	34 ± 1.5	17 ± 7.2	-17 ± 7.4	-50 ± 21

TABLE H-10
TRACE ELEMENT ANALYSIS (PPM)
FOX MINE
LOWER KITTANNING SEAM, CLARION COUNTY, PENNSYLVANIA

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	<.1	<.1	<.1	2.5	0.5	0.5	<.1	1.1 ± 1.1	+1.1 ± 1.1	N.D.
As	25.2	22.4	22.8	1.8	0.1	2.4	23.5 ± 1.5	1.4 ± 1.2	-22.1 ± 1.9	-94 ± 5
B	18	15	15	13	13	-	16 ± 1.7	13 ± 0	-3 ± 1.7	19 ± 9
Be	1.0	2.0	2.0	0.6	0.5	0.8	2.0 ± 0.6	0.6 ± 0.2	-1.4 ± 0.6	-70 ± 14
Cd	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cr	98	90	95	44	35	40	94 ± 4.3	40 ± 4.5	-54 ± 6.2	-58 ± 5
Cu	23	28	24	14	13	14	25 ± 2.4	14 ± 0.6	-11 ± 2.5	-44 ± 6
F	92	95	-	82	82	-	93.5 ± 2.1	82 ± 0	-11.5 ± 2.1	-12 ± 2
Hg	0.07	0.07	0.06	0.14	0.18	0.14	0.07 ± 0.01	0.15 ± 0.02	+0.08 ± 0.02	Gain
Li	4	4	4	15	15	14	4 ± 0.1	15 ± 0.6	+11 ± 0.6	Gain
Mn	25	26	21	8	8	10	24 ± 2.5	9 ± 1.2	-15 ± 2.8	-63 ± 6
Ni	153	146	143	10	12	10	147 ± 5.1	11 ± 1.1	-136 ± 5.2	-93 ± 1
Pb	7	7	2	12	11	12	5 ± 2.9	12 ± 0.6	+7 ± 3	Gain
Sb	<1	<1	<1	<1	<1	<1	<1	<1	Ind	Ind
Se	18	10	24	<2.5	<2.5	<2.5	17 ± 7.2	<2.5	>-15 ± 7.2	>-85%
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	85	12	102	105	125	115	94 ± 11.8	115 ± 10	+21 ± 15	Gain
Zn	113	104	99	11	11	10	105 ± 7.1	11 ± 0.6	-94 ± 7.1	-90 ± 1

TABLE H-11
TRACE ELEMENT ANALYSIS (PPM)
WARWICK MINE
SEWICKLEY SEAM, GREENE COUNTY, PENNSYLVANIA

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	6	4	2	2	2	1	4 ± 2.0	2 ± 0.6	-2 ± 2.1	N.D.
As	13.5	13.5	11.8	<.1	<.1	<.1	12.9 ± 1.0	<.1	-12.9 ± 1	~-100
B	20	20	-	20	13	-	20 ± 0	16 ± 4.9	-4 ± 4.9	-18 ± 25
Be	1	1	1	1.2	0.4	0.6	1 ± 0.0	0.7 ± 0.4	-0.3 ± 0.4	N.D.
Cd	<.5	1	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cr	84	78	80	48	50	46	81 ± 3.0	48 ± 2	-33 ± 3.6	-41 ± 4
Cu	24	24	23	24	18	18	24 ± 0.6	20 ± 3.5	-4 ± 3.6	N.D.
F	245	257	-	177	161	-	251 ± 8.5	169 ± 11	-82 ± 14	-33 ± 6
Hg	0.14	0.12	0.15	0.06	0.06	0.12	0.14 ± 0.02	0.08 ± 0.03	-0.06 ± 0.036	-43 ± 23
Li	81	68	78	60	57	63	76 ± 6.8	60 ± 3	-16 ± 7.4	-21 ± 8
Mn	30	32	31	18	18	16	31 ± 1.0	17 ± 1.1	-14 ± 1.5	-44 ± 4
Ni	48	42	42	23	22	20	44 ± 3.5	22 ± 1.5	-22 ± 3.8	-51 ± 5
Pb	18	15	16	12	10	8	16 ± 1.5	10 ± 2	-6 ± 2.5	-38 ± 14
Sb	<1	<1	<1	<1	<1	<1	<1	<1	Ind	Ind
Se	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	85	75	75	95	75	105	78 ± 5.8	92 ± 15.3	+14 ± 16	N.D.
Zn	57	54	55	18	18	17	55 ± 1.5	18 ± 0.6	-37 ± 1.6	-67 ± 2

TABLE H-12
TRACE ELEMENT ANALYSIS (PPM)
HUMPHREY NO. 7 MINE
PITTSBURGH SEAM, MONONGALIA COUNTY, WEST VIRGINIA

ELEMENT	INDIVIDUAL VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	0.5	0.5	(<.1)	0.5	0.5		0.5	0.5	0	0
As	9.1	9.1	9.1	0.7	0.7	0.9	9.1 ± 0	0.8 ± 0.1	-8.3 ± 0.1	-91 ± 1
B	28	24	-	17	15		26 ± 2.8	16 ± 1.4	-10 ± 3.1	-38 ± 9
Be	0.4	0.4	0.5	0.4	0.4		0.4 ± 0.06	0.4 ± 0	0	N.D.
Cd	<.5	<.5	<.5	<.5	<.5		<.5	<.5	Ind	Ind
Cr	26	25	27	20	26		26 ± 1.0	24 ± 3.8	-2 ± 3.9	N.D.
Cu	18	15	-	14	17		16 ± 2.1	16 ± 2.1	0	N.D.
F	81	76	-	97	67		78.5 ± 3.5	82.0 ± 21	+3.5 ± 21	N.D.
Hg	0.07	0.07	0.04	0.16	0.16	0.18	0.06 ± 0.02	0.17 ± 0.01	+0.11 ± 0.02	Gain
Li	14	13	12	11	12		13 ± 1.0	12 ± 0.7	+1 ± 1.2	N.D.
Mn	32	32	30	6	8		31 ± 1.1	7 ± 1.4	-14 ± 1.8	-77 ± 5
Ni	18	18	14	9	10		17 ± 2.3	10 ± 0.7	-7 ± 2.4	-41 ± 9
Pb	8	6	6	2	19		7 ± 1.1	11 ± 12	+5 ± 10	N.D.
Sb	<1	<1	<1	<1	<1		<1	<1	Ind	Ind
Se	<2.5	<2.5	<2.5	<2.5	<2.5		<2.5	<2.5	Ind	Ind
Sn	<2.5	<2.5	<2.5	<2.5	<2.5		<2.5	<2.5	Ind	Ind
V	55	85	90	40	55		77 ± 18.9	48 ± 10.6	-29 ± 22	-38 ± 21
Zn	16	14	23	7	9		18 ± 4.7	8 ± 1.4	-10 ± 4.9	-56 ± 14

TABLE H-13

TRACE ELEMENT ANALYSIS (PPM)

BELLE AYR MINE, ROLAND-SMITH SEAM, CAMPBELL CO., WYOMING

ELEMENT	IND VALUES						AVERAGE VALUES		PPM CHANGE	% CHANGE
	UNTREATED			TREATED			UNTREATED	TREATED		
Ag	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	Ind	Ind
As	1.0	0.08	0.07	0.7	0.7	0.7	0.4 ± 0.5	0.7 ± 0.0	+0.3 ± 0.5	N.D.
B	17.0	5.0	10.0	10	<5	-	11 ± 6	3 ± 5.7	-8 ± 8.3	N.D.
Be	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	Ind	Ind
Cd	<.5	.8	1.0	<.5	<.5	<.5	0.6 ± 0.5	<.5	>-0.1 ± .5	N.D.
Cr	<.5	<.5	<.5	4	6	4	<.5	5 ± 1.1	+4.5 ± 1.1	Gain
Cu	28	29	25	23	20	22	27.3 ± 1.5	22 ± 1.5	-5.3 ± 2.1	-19 ± 7
F	51.0	45.7	47.0	23.9	29.6		47.9 ± 2.8	26.8 ± 4.0	-21.1 ± 4.9	-44 ± 9
Hg	0.24	0.19	0.22	0.14	0.14	0.12	0.22 ± .02	0.13 ± .01	-.09 ± .02	-41 ± 7
Li	<.3	<.3	<.3	2	2	2	<.3	2 ± 0	+1.7 ± 0	Gain
Mn	34	55	55	4	4	4	48 ± 12.2	4 ± 0	-44 ± 12.2	-92 ± 26
Ni	40	80	63	10	4	7	61 ± 19.7	7 ± 3	-54 ± 20	-89 ± 6
Pb	3	2	5	11	8	11	3 ± 1.5	10 ± 1.6	+7 ± 2	Gain
Sb	2	<1	4	<1	<1	<1	2 ± 1.8	<1	>-1 ± 1.8	N.D.
Se	12	3	<2.5	<2.5	<2.5	<2.5	5 ± 6.6	<2.5	>-2.5 ± 6.6	N.D.
Sn	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	Ind	Ind
V	0.8	1.3	<.5	10	15	10	1 ± 0.6	12 ± 2.9	+11 ± 3	Gain
Zn	54	49	44	3	2	3	49 ± 5.3	3 ± 0.6	-46 ± 5.3	-94 ± 1